MANUALS OF TELEGRAPH AND TELEPHONE ENGINEERING

Edited by SIR WILLIAM SLINGO

LATE ENGINEER-IN-CHIEF TO GENERAL POST OFFICE

THE INSPECTION AND TESTING OF MATERIALS, APPARATUS AND LINES

THE INSPECTION AND TESTING OF MATERIALS, APPARATUS AND LINES

BY

F. L. HENLEY
STAFF ENGINEER, GENERAL POST OFFICE, LONDON
MEMBER OF THE INSTITUTION OF ELECTRICAL ENGINEERS

WITH 151 *DIAGRAMS*

LONGMANS, GREEN AND CO.
39 PATERNOSTER ROW, LONDON, E.C. 4
NEW YORK, TORONTO
BOMBAY, CALCUTTA AND MADRAS
1923

Made in Great Britain

PREFACE

THE testing and inspection of material and apparatus in a large organization like the British Post Office is an important operation and provides employment for a large number of men. Many of them are regularly employed on this work, while a large number of others are called upon occasionally to assist with the duties. This book has been written, therefore, with a view to providing a description of the methods employed and the requirements to be met; but owing to the wide range of items involved it is not possible to include in this volume a detailed description of all of them. It is hoped that the selection which has been made will prove of general use and interest. The book covers no examination syllabus and is intended solely to meet the requirements of Telephone and Telegraph men. It must be distinctly understood that the opinions expressed are the writer's own and carry no official authority. Wherever it has been considered desirable, popular descriptions of manufacturing processes have been introduced because experience has proved that good general notions on these subjects are of great help to the inspector of materials.

The writer desires to thank Colonel T. F. Purves, Engineer-in-Chief to the Post Office, for his kind permission to publish extracts from Post Office specifications and technical instructions and to reproduce certain official diagrams.

He is also indebted to his colleagues in the Test Section for much valuable help in compiling the details of the tests, and especially to Captain Legg and Messrs. W. H. Winny, D. Stuart, H. A. Miles, F. H. Bailey, S. Hanford, F. H. Buckland, T. F. Day, A. J. Bell, R. Greenstreet, J. Jupp, A. J. Barker, H. Davis, and A. L. Hook.

In the body of the book frequent reference is made to standard works, but a bibliography has not been attempted because the task was too formidable.

Any suggestions for improving the book, so that it will be more useful to Telephone and Telegraph men, will be gladly received by the writer, either from his colleagues in the Post Office or his friends in the Colonial services.

F. L. H.

TEST SECTION,
ENGINEERING DEPT., G.P.O. (WEST),
July, 1923.

CONTENTS

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER IV

CHAPTER V

CHAPTER VI

CHAPTER VII

CHAPTER VIII

CHAPTER IX

CONTENTS

CHAPTER X

CHAPTER XI

CHAPTER XII

CHAPTER XIII

CHAPTER XIV

CHAPTER XV

CHAPTER XVI

CHAPTER XVII

CHAPTER XVIII

LIST OF PLATES

CHAPTER I

INTRODUCTION

As a general principle it may be said that the Post Office Department purchases its supplies of Telephone and Telegraph apparatus and material under competitive conditions. Invitations to tender are issued to manufacturers, and the contract is made with the manufacturer quoting the lowest price. This method of purchasing involves among other things that the manufacturers shall be furnished with a detailed and accurate description of the material or apparatus to be supplied, in order that they may compete on equal terms, and implies that in justice to the manufacturers whose tenders are declined that nothing inferior to the standard tendered for shall be accepted by the Post Office Department. The basis of the contract, therefore, is a definite specification, and in the case of apparatus a specification, a detailed drawing, and a pattern to show the finish required. The inspection and testing of supplies follows as a corollary, even if the efficiency of the telephone and telegraph services did not depend upon efficient apparatus and suitable materials. The specifications are drafted and the drawings approved by the technical sections of the Engineering Department responsible for the maintenance and efficiency of the several parts of the system, and are co-ordinated and controlled by the Designs Section. The contracts for stores are placed by the Stores Department of the Post Office, but if construction work needing supervision on site is involved the contracts are placed by the Contracts Branch of the Engineering Department. The latter are known as Engineers' Orders and the former as Stores' Contracts. The apparatus and materials supplied under both Engineers' Orders and Stores' Contracts are inspected and tested by the Test Section of the Engineering Department. Fully-equipped Mechanical, Chemical, and Electrical Testing Branches are provided for this purpose in London and Birmingham adjacent to the Stores Department's depots, and all supplies are inspected and tested. With regard to telephone apparatus, it is convenient to test the bulk of this at the manufacturer's works, and quite a large proportion of the Test Section staff is employed on this work, the manufacturers providing the necessary testing apparatus and accommodation free of charge. Paper core and other cables are also tested at the works of the manufacturers by officers of the Test Section.

Wherever definite figures can be specified for mechanical strength, electrical properties, and composition this course is followed and the necessary tests are made. These will be found under their appropriate headings in the following chapters. In many cases, however, an accurate estimate of the suitability of apparatus and material cannot be reduced to a system of figures, and it is here that the judgment and experience of the Inspecting Officer are called into play. The more he knows of manufacturing processes, of the properties of materials, of craftsmanship, and of the requirements of the telephone and telegraph services, the better able will he be to form an accurate judgment and to steer clear of rejecting satisfactory supplies or of approving anything unsatisfactory. The training of Inspecting Officers in a large organisation like the Post Office is a matter of considerable importance, and it may be said that before the inspectors are called upon to act upon their own judgment they have always been employed on inspection work for several years under the supervision of a thoroughly qualified inspector. A properly trained man will detect discrepancies that an untrained man will frequently fail to notice. Where repetition processes of manufacture are largely followed, as in telephone parts, it is highly desirable that any discrepancy should be discovered in the first batch of parts delivered, so that the error may be remedied before a large number of such parts have been made. It is the practice, therefore, to make what is described as a priority examination of the first batch delivered, which consists of selecting at haphazard half a dozen of the delivery and subjecting these to an immediate and expert critical examination. If any departures from the drawing, pattern, or specification are found, the manufacturer is promptly advised of the facts. This method of procedure is of advantage to the manufacturer and also to the Post Office, because it prevents the discrepancies being duplicated in the parts under manufacture, and prevents undue delay in the supply of satisfactory parts.

In addition to possessing the necessary technical knowledge an Inspecting Officer is required to exercise courtesy and tact, especially as it is frequently his duty to convey decisions to contractors of an unwelcome kind, and overstatement of his case on these occasions may lead to strained relations. The expert inspector notices the merits as well as the demerits of a manufacturer's product, and in communicating an adverse decision he finds it possible and advisable to mention the former as well as the latter. When a manufacturer's foreman has made an honest effort to turn out a good job, he is more than disappointed if any little defects or errors that may be found are unduly magnified by the inspector, whilst the obvious good work is passed over without comment. High qualifications are undoubtedly required for the expert inspection of Telephone and Telegraph materials, and there is practically no limit to the different kinds of knowledge which an inspector can usefully employ in his work. The wider his scientific knowledge is, the more interesting will his daily work be, for whatever of Chemistry,

Mechanics, Physics, and Mathematics he may know, he will find abundant opportunities to apply practically. Although the mechanical and electrical tests that he will use are for the most part of a routine and simple character, applied merely to ascertain whether the material or apparatus reaches the standard defined in the specification, there will be plenty of opportunity of applying his knowledge to form judgments on those points respecting quality, finish, and workmanship where simple tests are not available and where wide knowledge is the best guide. An effort has been made to treat the question of testing from this point of view in the early chapters of the book, and to provide the reader with a fairly comprehensive account of the manufacture of the principal engineering materials, and of the distinguishing characteristics of these materials. It would have been comparatively easy to compile a series of routine tests in a form something like cookery-book recipes, but the value of such a series would be comparatively small, and it would be tedious to write and read. The narrative form has been adopted deliberately, as far as the subject would permit, and it is hoped that the book will prove an interesting companion in the train as the inspector travels from town to town. In Chapter II the case of a circular rod or beam has been dealt with, because this is the form in which the Telephone and Telegraph Inspector frequently meets the case, but it has necessitated the use of symbols that may be unfamiliar. It is hoped, however, that if this is the case, the reader will persevere with this chapter, and if there is anything he cannot understand in it, will compare what is said in Chapter II with one of the standard works on the subject, such as Unwin's "Testing of Materials of Construction" or Ewing's "Strength of Materials," where rectangular sections are fully dealt with, on much the same lines as those followed in this book, but more thoroughly and comprehensively. It is often found that an idea which is difficult to comprehend when met with for the first time becomes quite clear to the reader on comparing one description with the other.

In describing the manufacturing processes a knowledge of elementary chemistry has been assumed, but if the reader has any difficulty in following the text his remedy is to read a couple of good works like Newth's "Inorganic Chemistry" and Remsen's "Organic Chemistry," when his difficulty will easily be overcome. The properties of materials depend so largely upon composition that a little knowledge of chemistry is by no means a dangerous thing, and although the reading of books will not, it is admitted, be a sufficient equipment for anyone aspiring to be a chemist, it will provide a knowledge of chemical properties that will be found very useful by an inspector of materials.

Machine telegraphs are being dealt with in another volume of this series, and although the apparatus is tested by the Test Section, the subject is not dealt with in this book, as the tests could not be adequately described without including a detailed description of the apparatus, for which sufficient space is not available. Similarly

the section on "Lines" covers only the ordinary maintenance testing, the subject of cable balancing and telephone transmission being dealt with in other volumes of the series.

The writing of the book has provided evening occupation for quite a long period, and it is believed that a better result would have been obtained if more leisure had been possible in which to complete the work. Although conscious of many of its shortcomings, the writer hopes that it will prove of service to his colleagues.

CHAPTER II

STRESS AND STRAIN

WHEN two particles or portions of matter act and react upon each other tending to alter their relative positions, the medium between them is said to be in a state of *stress*. The portions of matter may or may not be parts of the same solid body. Every state of stress comprises two aspects, each aspect consisting of matter acted upon by a force. The stress may tend to produce either attraction or repulsion, and hence to cause a compression or a tension respectively in the medium between the portions of matter. If a rod be gripped at the two ends and forces be applied to the ends tending to stretch the rod, the cohesive force of the particles of the rod will resist the forces applied, and a state of equilibrium will result if the magnitude of the forces is within certain limits. The forces applied at the ends set up a state of stress along the rod, and if the forces are uniformly distributed over the cross-sectional area the intensity of stress is defined as the force per unit of area of cross-section. Hence if the total pulling force at one end is P units, and this is uniformly distributed over A square units of cross-section, the intensity of stress (p) is $\frac{P}{A}$.

Tension.—Let AB in Fig. 1 represent a rod held firmly at A, and let a force acting at B stretch the rod until the total length becomes AC. If AB is x units in length, and BC U units in length, the *average* stretch or extension *per unit of length* is $\frac{U}{x}$, which ratio may be denoted by the letter S:

$$S = \frac{U}{x} = \frac{BC}{AB},$$

but it is not necessarily uniform throughout the whole length of the rod. If the extension does not exceed a certain limit, which will be referred to later, we may when dealing with homogeneous material of uniform cross-section obtain a similar equation in a different way. At any point in AB take an infinitesimal length dx, and let this length be increased by the stretching forces to $dx + du$. The total extension at this point is du, and the extension per unit of length

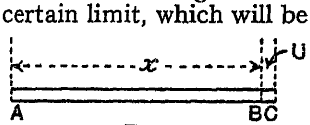


FIG. 1.

(at this point) $\frac{du}{dx}$. If the extension at every point of the rod is uniform, we may equate $\frac{du}{dx}$ to S.

$$S = \frac{du}{dx}$$

$$\therefore S \, . \, dx = du,$$

and since we know we are dealing with a straight pull, we may integrate this and obtain

$$S\int_{0}^{AB} dx = \int_{0}^{BC} du$$

$$\therefore S \, . \, AB = BC$$

$$S = \frac{BC}{AB} = \frac{U}{x}.$$

In this case the value of S is accurate for each unit of length, and not an average value as in the previous case. The assumption made in the equation

$$S = \frac{du}{dx},$$

when we integrate, is that in every infinitesimal length dx of the rod the extension is the same as in every other equal infinitesimal length dx of the rod. In practical work this condition is only met with when the material is stretched within certain limits, and in these cases, if the stretching forces be lessened until they become zero, the rod will then return to its original unstretched length AB. In the first case this condition was not assumed. Within the limits mentioned the material obeys Hooke's law that stress is proportional to strain. The *strain* in this case is the stretch per unit of length (S), and Hooke's law may be written :

$$p \propto S;$$

or by using the algebraic rule for *variations* we may multiply S by a constant and obtain the equation

$$p = E \, . \, S.$$

This equation is of the same form as

$$y = mx,$$

which is shown in books on co-ordinate geometry to be the equation of a straight line passing through the origin. The constant E is generally referred to as Young's modulus, and its value has been ascertained for a large number of materials. It is perhaps unnecessary to say that the value of E is different for different materials. The limit of stretch up to which this proportionality or straight line law holds is referred to as the elastic limit, since no persistent

deformation of the material is found when the stretching forces no longer operate. If the material be stretched beyond this limit it will no longer return to its original length when the stretching forces are taken off, a part of the extension being permanent, and this part is generally referred to as permanent set. The diagram shown in Fig. 2 will serve to illustrate what is meant.

As the stretching forces or load increase from O to OA the stretch or extension increases from zero to OB, and the line OF is straight. Had the load been taken off at any value less than OA, the stretch would have decreased to zero, that is to say, the rod would have returned to its unstretched length. Increasing the load beyond the value OA causes the material to yield permanently, and the part FG of the curve is sometimes referred to as the yield point of the material. By increasing the value of the load still further the part GH of the curve is obtained, the extension consisting mainly of plastic deformation of the material, which remains after the load is taken off. At the point H on the curve there is a local contraction at one section of the rod, and at this place the rod will eventually break at a load somewhat lower than the maximum reached during the test. The part HK of the curve is a rough measure of this local effect, and serves as a guide to the degree of toughness of ductile materials. It is important to remember that Hooke's law holds good for only that part of the diagram represented by the straight line OF, and it is only to this part that the equation

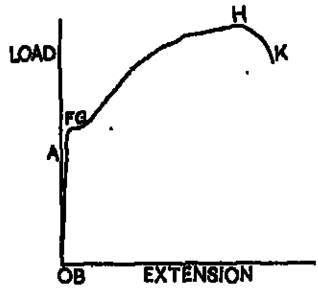


Fig. 2.

$$p = E \cdot S$$

applies. In determining the value of E for any given material, considerable care is necessary to prevent errors due to want of straightness of the sample affecting the result. For this reason it is convenient to employ for the purpose a straight wire about 14 inches long and about $\frac{1}{4}$ inch diameter, the determination of E being made by means of an extensometer of the Ewing or other standard type. A description of the Ewing extensometer will be found in Ewing's "Strength of Materials." If an extensometer is not available, it is necessary to employ a very long length of wire. The following example will show how the calculation is made. A hard copper wire 50 feet long, 158 mils diameter, was subjected to a load of 60 lbs., when the elastic extension was found to be 0·105 inch, what is the value of E?

$$E = \frac{\text{stress}}{\text{strain}} = \frac{\dfrac{60}{\cdot 0196\ (\text{area})}}{\dfrac{0\cdot 105}{50 \times 12}} = 17\cdot 5 \times 10^6.$$

The figures do not represent an actual experiment, although the value $17 \cdot 5 \times 10^6$ is approximately correct. The elastic strains, therefore, are very small, and the constant is mostly of value where it is desired to calculate strains from known stresses by the equation

$$S = \frac{p}{E},$$

or for calculating stresses from measured strains by the equation

$$p = E \cdot S.$$

Tension Tests.—It is generally sufficient in commercial testing to determine the following:—

(1) Breaking load (calculated to tons per square inch).
(2) Extension per cent. (usually on a length of 8 inches).
(3) Reduction in area per cent. at the fractured surface.

The breaking load in tons per square inch is calculated on the original section of the material, that is to say, the area of the cross-section of the rod or other sample before the test is made. This is the most convenient method to follow, although it would be possible to calculate the breaking load in tons per square inch on the area of the fractured sample. The figure obtained from the latter calculation, however, would not be the breaking load in tons per square inch at the instant of fracture, because part of the local contraction is almost certainly elastic, and this part could not be accurately determined. The yield point is seldom specified, and the British Engineering Standards Association after investigating the matter have decided that the yield point for commerical purposes cannot be satisfactorily defined for engineering materials. The practical engineer works well inside the limit where the yield point of the material is likely to take place. The usual practice, therefore, is to ascertain the breaking weight in tons per square inch, and to adopt a working strength which will ensure that the material is not overstrained. The ratio

$$\frac{\text{Working strength in tons per square inch}}{\text{Breaking weight in tons per square inch}}$$

is accordingly a proper fraction, and when the numerator is 1 the denominator is generally referred to as the factor of safety, that is to say, if we take the breaking weight of a given material at 24 tons per square inch, and the working strength at 6 tons per square inch, the factor of safety is 4. Rolling, drawing, hammering, and machining generally tend to harden materials, and when materials are hardened the yield point of the material is, as a rule, raised. The yield point is consequently variable for most engineering materials which pass through commercial processes, and cannot be safely predicted for all samples.

Extension Per Cent.—Generally two small marks made with a

punch are sufficient for marking off the 8-inch length on which the extension after test is to be measured, but occasionally marks are made at every inch for 8 inches when it is desired to ascertain how the sample has behaved near the fracture. The extension on the inch length in which the fracture occurs is greater than in any other inch length for most of the ductile materials, and, as a rule, the farther away from the fracture the extension per inch is measured, the less it is found to be.

Reduction in Area per Cent.—The diameter of the fractured surface is carefully measured by means of a micrometer screw gauge, and the difference in area calculated as a percentage of the original area.

Compression.—Some materials behave under compression stresses in the same way that they do under tension stresses, and in these materials the value of Young's modulus (E) is the same for compression as for tension. There are some materials of which cast iron is perhaps the most noteworthy, where the breaking strength in compression is much higher than in tension. In compression tests applied to samples where the length of the sample is equal to, or only two or three times as great as, the diameter of the cross-section, brittle materials give way under a complex stress, which is made up of tangential stresses along certain planes, which can be approximately predicted by theoretical considerations. In Fig. 3 let ABCDEF be a cube of the material to be tested, and let compressive forces act uniformly over the faces ABF and DCE as indicated diagrammatically by the arrows, it being assumed that the forces are uniformly distributed over the faces. If we consider the forces acting on the imaginary plane ACE, we can at any point resolve the compressive force normally and tangentially to this plane, that is to say, if P is the total force acting uniformly over the plane ABF,

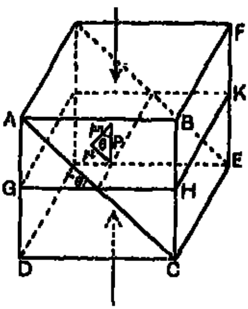


FIG. 3.

the force p per unit of area is $\frac{P}{\text{Area ABF}}$ or $\frac{P}{\text{Area GHK}}$, and if θ is the angle between the planes GHK and ACE, or, what amounts to the same thing, the angle between the normals to these planes, then

$$\text{Area GHK} = \text{Area ACE} \cdot \cos\theta$$
$$\text{Area ACE} = \frac{\text{Area GHK}}{\cos\theta}.$$

The component of P normal to the plane ACE is P cos θ, and this acts uniformly over the plane ACE, hence the normal component per unit of area is

$$p_n = \frac{P\cos\theta}{\text{Area ACE}} = \frac{P\cos\theta}{\frac{\text{Area GHK}}{\cos\theta}} = \frac{P\cos^2\theta}{\text{GHK}},$$

but $\frac{P}{GHK} = p$. Therefore $p_n = p \cos^2 \theta$, and the tangential component per unit of area is

$$p_t = \frac{P \sin \theta}{\text{Area ACE}} = \frac{P \sin \theta}{\frac{\text{Area GHK}}{\cos \theta}} = \frac{P \sin \theta \cos \theta}{GHK} = p \sin \theta \cos \theta.$$

To find the angle for which p_t is a maximum differentiate p_t with respect to θ and equate to zero,

$$\frac{d(p_t)}{d\theta} = pd(\sin \theta \cos \theta) = \frac{p}{2} d(\sin 2\theta) = p \cos 2\theta = 0,$$

since p cannot in this case be 0, $\cos 2\theta = 0 = \cos 90°$. Therefore $\theta = 45°$.

Hence $p_t = p \cos 45° \sin 45° = p \sqrt{\tfrac{1}{2}} \sqrt{\tfrac{1}{2}} = \frac{p}{2}$, that is, the maximum tangential force should develop according to this theory on planes at 45° to the plane ABF, and be of value $\frac{p}{2}$ where p is the intensity of stress on the planes ABF and DCE. Cubes of Portland cement, when tested in compression rupture somewhat in this way, but the angles are greater than 45°, and it has been suggested by Professor Perry * that the greater angle is probably due to there being a resistance to shearing of the nature of friction. Accurate results in compression testing are obtained only when the forces are uniformly distributed over the opposite faces of the sample and act normally to them. These conditions are difficult to comply with even in the case of a material which can be so readily moulded as Portland cement, and up to the present compression tests on brittle materials have seldom been specified. With materials that show a plastic yield such as copper and its alloys, compression tests are seldom made, as these materials simply squeeze down to small thickness with rounded edges, and the yield point under compression is difficult to determine, unless expensive testing apparatus is available for the purpose.

Bending Moment.—A force acting at the end of a cantilever may be regarded as being composed of an equal parallel force acting at any other part of the cantilever, together with an appropriate couple.

Let AB be a rod fixed at A and loaded at B with the weight W. Then if at any other place between A and B, say C, equal and opposite forces W parallel to the force at B be applied, the stability of the system will not be disturbed. In effect we have transferred the force W from B to C and added a couple W × BC. The downward force W at C is generally referred to as the shearing force at the part C, and the force W is resisted by the cohesion of the particles of the material. The couple W × BC is called the bending moment

* "Applied Mechanics," par. 290, p. 345.

(M) at the part C, due to the weight W acting at B. Since C is any point in AB, we can construct a diagram showing how the bending moment varies as we pass from B to A. It is zero at B since C coincides with B at this point, and it is a maximum at A. The diagram of bending moment in this case is therefore a triangle. Since the shear has the same value at all points between A and B, the diagram representing the shear is a rectangle.

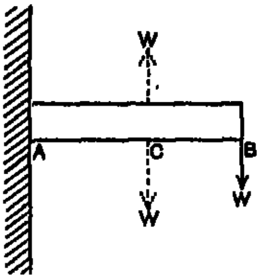


FIG. 4.

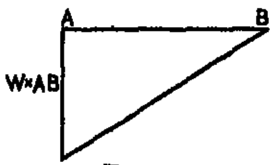


FIG. 5.

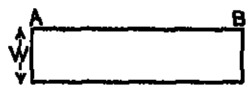


FIG. 6.

If AB = l units in length, the bending moment M at A due to the load W acting at B is

$$M = Wl,$$

and the shearing force at any point between A and B is W units. Inches and pounds are usually employed in calculating bending moments.

If the load W be applied in the middle of a rod supported at its two ends, the load will be carried by the supports equally, hence $\frac{W}{2}$ will act at A and also at B.

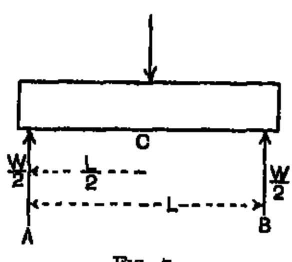


FIG. 7.

The leverage at A and also at B is $\frac{l}{2}$, hence the bending moment at the middle C is

$$M = \frac{W}{2} \times \frac{l}{2} = \frac{Wl}{4}.$$

If we take moments about the support A and regard that direction as positive which is in a clockwise sense, we have

$$\frac{W}{2}\times o + W\times\frac{l}{2} - \frac{W}{2}\times l = o,$$

and about the point C we have

$$\frac{W}{2}\times\frac{l}{2} - \frac{W}{2}\times\frac{l}{2} = o,$$

proving that the assumptions made are correct. The diagram of bending moment may be shown as

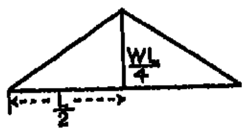


FIG. 8.

and the shear diagram

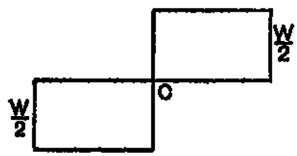


FIG. 9.

In this case the shear at no place exceeds $\frac{W}{2}$. At the point C, where the shear changes sign, the load is not applied at a geometrical point, but is distributed over a finite length, and Professor Ewing, in his "Strength of Materials," points out that the change from positive to negative shearing force would be gradual over that length.

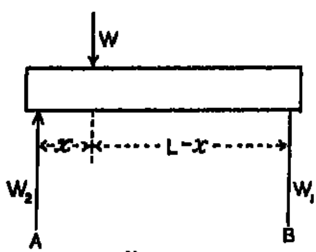


FIG. 10.

If the load W be applied at any point other than the middle, the loads on the two supports will be unequal and inversely proportional to the distances of the load W from the supports.

Taking moments about the support A,

$$Wx - W_1 l = o, \text{ or } W = W_1\frac{l}{x}.$$

Taking moments about the support B,

$$W_2 l - W(l - x) = o, \text{ or } W = W_2\frac{l}{l-x},$$

$$\therefore W_1\frac{l}{x} = W_2\frac{l}{l-x},$$

and
$$\frac{W_1}{W_2} = \frac{x}{l-x}.$$

Maximum bending moment $M = W_2x = W_1(l-x) = \dfrac{W(l-x)x}{l}$

since
$$W = W_2\frac{l}{l-x} = W_1\frac{l}{x}.$$

The shear will be determined by the loads on the supports, and will change sign where the load is applied.

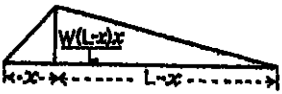


FIG. 11.

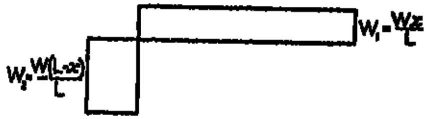


FIG. 12.

Deflections.—In Fig. 13 let ABCD be an end view of a circular rod, the line AB representing the trace of a horizontal plane through

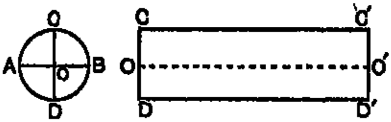


FIG. 13.

the length of the rod and CD a vertical plane, the two planes intersecting in the central axis OO′. If this rod be bent into the arc of a circle the plane CC′DD′ will be stretched along the line CC′ and compressed along the line DD′, whilst the length of the axis or middle line of the plane will remain unchanged.

Any other parts above and below the plane AB will be subject to the same kind of deformation as CC′ and DD′ respectively, but in less degree. The plane AB is called the neutral plane and the line OO′ the neutral axis. In most homogeneous materials the value of Young's modulus (E) is the same for tension as for compression, and consequently the strains of the outermost fibres, i.e. along the lines CC′ and DD′, are equal. If ρ is the radius of the circle of curvature, and θ the angle subtended by the bent rod, then the length of the neutral axis is $\rho\theta$, the length of CC′ after

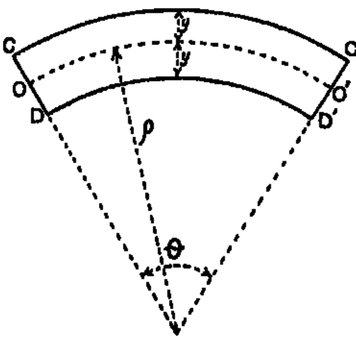


FIG. 14

nding is $(\rho + y')\theta$, and of DD′ $(\rho - y')\theta$. The increase in length CC′ is therefore $y'\theta$, and the decrease in length of DD′ is also $y'\theta$. ne strain or stretch per unit length along CC′ is $\frac{y'\theta}{\rho\theta} = \frac{y'}{\rho}$, and similarly the strain or compression per unit length along DD′ is $\frac{y'}{\rho}$, and from Hooke's law we may write

$$p = E\frac{y'}{\rho}$$

where p is the stress along the line CC′ or DD′. The strain rom a maximum along CC′ to zero along OO′, and then a maximum along DD′. Since the strain is directly pro- o y, it may be represented at any point by means of a

point y the strain will be $\frac{y\theta}{\rho\theta} = \frac{y}{\rho}$, providing we assume ne sections remain plane after the rod is bent, and that the strain is within the elastic limit. The stress at any point y at a perpendicular distance oy from the neutral plane is

$$p = \frac{Ey}{\rho},$$

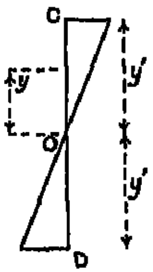


FIG. 15.

and if we take this force as acting on an element of area da, we have

$$p \,.\, da = \frac{Ey}{\rho}da,$$

but this force has a moment about the neutral plane, so that to provide for this the expression must be multiplied by y, the perpendicular distance from the neutral plane. We then have for this element of area the moment

$$dM = \frac{Ey^2}{\rho}da,$$

and to find the total moment over the cross-section this expression must be integrated. $\frac{E}{\rho}$ is constant,

$$\therefore M = \frac{E}{\rho}\iint y^2 da,$$

and Fig. 16 will show the solution.

Taking AB as the horizontal diameter of the circular rod and O as the centre, consider the elementary area $dr \times ds$ in the elementary sector of the circle at distance r from the centre, and perpendicular distance y from AB.

Then $y = r \sin \theta$, and from the relationship

$$\frac{\text{arc}}{\text{circumference}} = \frac{\text{angle in radians}}{2\pi \text{ radians}}$$

$$\text{arc} = \frac{2\pi r \times \text{angle}}{2\pi} = r\theta$$

$$\therefore ds = r \,.\, d\theta.$$

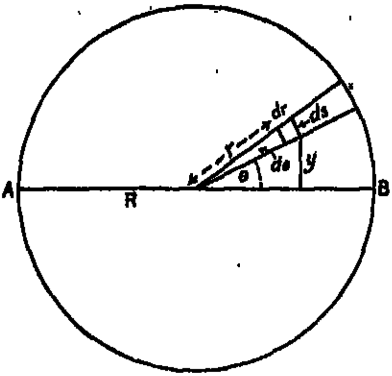


FIG. 16.

Hence

$$y^2 da = r^2 \sin^2 \theta dr ds,$$

since $\qquad y = r \sin \theta$

and inserting value for ds

$$y^2 da = r^3 dr \sin^2 \theta d\theta$$

$$\int_0^R \int_0^{2\pi} r^3 dr \sin^2 \theta d\theta = \int_0^R \int_0^{2\pi} r^3 dr \left(\frac{1 - \cos 2\theta}{2}\right) d\theta$$

$$= \left[\frac{r^4}{4} \cdot \frac{\theta}{2} - 0\right]_0^{R.\,2\pi} = \frac{R^4 \pi}{4},$$

$$\therefore M = \frac{E}{\rho} \iint y^2 da = \frac{E}{\rho} \times \frac{R^4 \pi}{4},$$

but by definition $\iint y^2 da$ is the moment of inertia,* and $\frac{R^4 \pi}{4}$ is the moment of inertia of a circle about a diameter. Inserting I for $\frac{R^4 \pi}{4}$, we have $M = \frac{E}{\rho} I$, or remembering the equations previously obtained,

$$\frac{M}{I} = \frac{E}{\rho} = \frac{p}{y'},$$

where y' is the perpendicular distance of the greatest strained fibre from the neutral plane. The ratio $\frac{I}{y'}$ is sometimes denoted by the letter Z, and is called the *modulus of resistance* of the section

$$M = pZ.$$

The theory holds only within the elastic limits, and is sometimes useful in calculating the deflection of unstayed poles when the stress at the top is known. The modulus of resistance is also a guide to the ultimate strength or breaking weight of a beam or cantilever,

* If in any system of particles the mass of each particle be multiplied by the square of its distance from a given line the sum of the products thus obtained is called the "moment of inertia" of the system with respect to that li

and instead of the factor p another factor appropriate to the breaking weight is used. This factor may be denoted by the letter C, so that in this case

$$M = CZ$$

where M now stands for the breaking moment and Z the modulus of resistance of the section. For pipes the moment of inertia can be obtained by subtracting the moment of inertia of the bore from the moment of inertia calculated on the external diameter, or

$$I(\text{about a diameter}) = \frac{\pi(R^4 - r^4)}{4},$$

where r is the internal radius of the pipe and R is the external radius, made up of the internal radius and one thickness of the pipe.

With regard to the curvature $\frac{1}{\rho}$ this is used in calculating deflections from the formula

$$\frac{M}{EI} = \frac{1}{\rho} = \frac{d^2y}{dx^2} \text{ (approximately)},$$

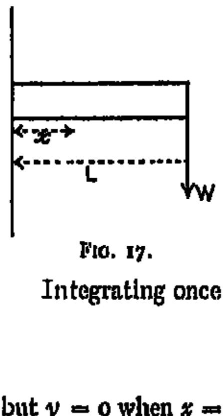


FIG. 17.

where y is the deflection and x the distance from the point of support in the case of a cantilever. The formula is true only for deflections within the elastic limit.

Take the case of a lever loaded at one end. Bending moment at x is

$$M = W(l - x)$$

$$\therefore \frac{M}{EI} = \frac{1}{\rho} = \frac{d^2y}{dx^2} = \frac{W}{EI}(l - x).$$

Integrating once we have

$$\frac{dy}{dx} = \frac{W}{EI}\left(lx - \frac{x^2}{2} + c\right),$$

but $y = 0$ when $x = 0$, and consequently the constant of integration c is zero. Integrating again,

$$y = \frac{W}{EI}\left(\frac{lx^2}{2} - \frac{x^3}{6} + d\right),$$

the constant d disappearing as in the previous integration. The deflection is greatest where $x = l$, that is,

$$y = \frac{W}{EI}\left(\frac{l^3}{2} - \frac{l^3}{6}\right) = \frac{Wl^3}{3EI}.$$

For a beam of rectangular section $I = \frac{BD^3}{12}$ where B is the breadth

and D the depth. Hence $y = \frac{4Wl^3}{EBD^3}$. Similarly, for a rectangular beam supported at the ends and loaded in the middle,

$$y = \frac{4\left(\frac{W}{2}\right)\left(\frac{l}{2}\right)^3}{EBD^3} = \frac{Wl^3}{4EBD^3} = \frac{Wl^3}{48EI}.$$

Simple Shear.—In Fig. 18 let ABCD, EFGH be a unit cube of homogeneous material subjected to equal forces PP′ QQ′ acting uniformly over the equal faces ABFG, BCEF, DCEH, and ADHG, the cube will then be subjected to a simple shearing stress.

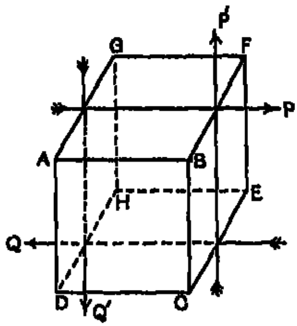


FIG. 18.

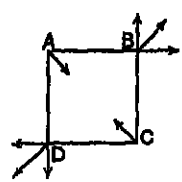


FIG. 18a.

It will be seen from the figure that the forces P and Q are parallel and constitute a couple P × BC, also P′Q′ constitute an equal couple P′ × AB, hence any lamina such as ABCD (Fig. 18a) will tend to elongate along the diameter DB and to contract along the diameter AC, and the change in the angle ADC or the angle DAB—assuming the material homogeneous and having equal values for Young's modules in compression and tension—is a measure of the strain. Within the elastic limit Hooke's law that stress is proportional to strain holds. If p be the stress per unit area, θ radians the strain per unit length, then $p \propto \theta$, and may be written $p = G\theta$. The constant G may be called the modulus of rigidity. It will be noticed that since Q and Q′ are equal, the resultant of QQ′ is a force $\sqrt{2}Q$, and if the diagonal plane ACEG be considered, it will be found that the equilibrant of $\sqrt{2}Q$ is a force in the opposite direction of intensity Q acting through the plane ACEG, which is $\sqrt{2}$ times the area of the face ADHG or DCEH. Similarly, on the plane DBFH there is a thrust of intensity Q to balance the resultant of P and P′. If the forces P and Q were the only two forces acting, the cube would tend to rotate, due to the couple P × BC, and consequently if there is no rotation the balancing couple P × AB must be present.

If we consider a rod of circular section supported at the two ends

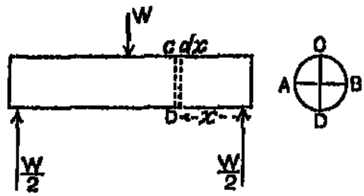
and loaded in the middle with a weight W, the bending moment at any place x units distant from one of the points of support is $\frac{W}{2}x$. If the neighbouring point $x + dx$ be taken, the bending moment is

$$M + dM = \frac{W}{2}(x + dx),$$

hence
$$dM = \frac{W}{2}dx,$$

and
$$\frac{dM}{dx} = \frac{W}{2},$$

which agrees with Fig. 9, where the shearing force is shown to be $\frac{W}{2}$.



FIGS. 19 and 19a.

To find that part of the *cross-section* of a circular beam where the shearing stress is a maximum.—This is best investigated by considering a beam supported at the ends and loaded evenly along its length, so that the shearing stress increases continuously from the middle of the span to a point of support. The shear at any section x units to the right of the middle of the span is, as already pointed out, the rate of change of the bending moment (M) with respect to x. It can be shown that the bending moment at x, in the case of a beam evenly loaded along its length, is

FIGS. 20 and 20a.

$$M = -\frac{wl^2}{8} + \frac{wx^2}{2}$$

where l is the length of the span, w the load per unit length, and x the distance measured from the middle of the span. The shear at this section is $\frac{dM}{dx} = wx$. Considering the elementary length dx along the neutral plane, the shearing stress for the total width of the neutral plane (2R) is $p \times 2R \times dx$, where p is the intensity of stress which has to be found.

From the equation $\frac{M}{I} = \frac{p}{y}$ the compressive or tensile stress at any point whose perpendicular distance from the neutral plane is y units is in this case

$$p = \frac{dM}{I}y,$$

and the force on an element of area da at this point is

$$p \cdot da = \frac{dM}{I} y da.$$

This expression requires to be integrated over the area of a semi-circle, which can be shown as follows :—

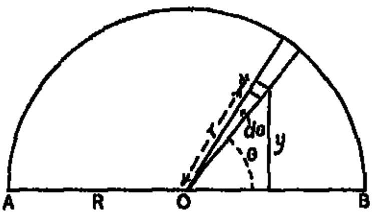


FIG. 21.

Take an elementary sector of the semi-circle OAB and consider the element of area $dr \cdot ds = r \cdot dr \cdot d\theta$. This element of area has to be multiplied by its perpendicular distance $y = r \sin\theta$ from the diameter. Hence

$$\iint y r dr d\theta = \int_0^R \int_0^\pi r^2 \sin\theta d\theta dr$$

$$= \frac{R^3}{3}\Big[-\cos\theta\Big]_0^\pi = \frac{R^3}{3}\Big[-(-1)-(-1)\Big] = \frac{2}{3}R^3,$$

and this expression is equal to the area of the semi-circle $\left(\frac{\pi R^2}{2}\right)$ multiplied by the distance of the centre of area from the neutral plane. Let the distance be $\overline{Y}$ units, therefore

$$\frac{2}{3}R^3 = \iint y da = \overline{Y}A = \overline{Y}\frac{\pi R^2}{2}$$

$$\overline{Y} = \frac{4}{3}\frac{R}{\pi}.$$

The centre of area, therefore, of the semi-circle at which the total force over the area may be regarded as acting is at a distance $\overline{Y}$ from the neutral plane, and since the area is symmetrical about a

line through the centre perpendicular to the neutral plane, $\overline{Y}$ lies along this line. Hence

$$\frac{dM}{I}\iint y\,da = \frac{dM}{I} \cdot \overline{Y} \cdot A, = \frac{dM}{I} \cdot \frac{4}{3}\frac{R}{\pi} \cdot \frac{\pi R^2}{2},$$

but I (about a diameter) $= \frac{\pi R^4}{4}$,

$$\therefore \frac{dM}{I} \cdot \frac{4}{3}\frac{R}{\pi} \cdot \frac{\pi R^2}{2} = \frac{dM}{\frac{\pi R^4}{4}} \cdot \frac{4}{3}\frac{R}{\pi} \cdot \frac{\pi R^2}{2} = \frac{dM \cdot 8}{3\pi R},$$

and this has to be equated to $p \cdot 2R \cdot dx$.

Hence

$$p \cdot 2R \cdot dx = \frac{8dM}{3\pi R}.$$

$$\therefore p = \frac{dM}{dx} \cdot \frac{4}{3} \cdot \frac{1}{\pi R^2}.$$

That is to say, along the neutral plane the value of p is a maximum since $p = \frac{4}{3}$ times the average shearing force at the section, because $\frac{dM}{dx}$ = shearing force at the section, and πR^2 is the area of the section.

The limits of integration in the above equation being R and O, if any other value than O, say r, is taken for the inferior limit, the value of p will be reduced, and p will vanish when $r = R$.

The value of the shearing force, therefore, decreases as the perpendicular distance from the neutral plane increases, and is zero at the top and bottom of a perpendicular to the plane through the neutral axis. Hence the stress due to the bending moment is zero along the neutral plane, but the shearing stress is a maximum, whereas at the greatest strained fibres the bending moment has its maximum effect, and the shear is zero.

Torsion.—If a circular rod be fixed at one end and a couple be applied at the other, the rod will twist, and within the elastic limit of the material the angle of twist will be proportional to the applied couple.

In Fig. 22 let ABC be a circular rod and ED a line on the surface parallel to the axis. If the result of the applied couple be to cause ED to move to EG, the arc GD is the total strain of the greatest strained fibre, and the strain per unit of length is $\frac{GD}{ED}$. ϕ is the angle of shear. Since O in Fig. 22*a* is the centre of a circle,

$$GD = OD \cdot \theta.$$

The total strain at any other point along OG is $r\theta$, where r is the distance from O along OG in the plane BDC.

The angle θ is connected with the angle ϕ as follows. In Fig. 22 consider two normal plane sections HK and LM, where HL is an element of length dx.

Then

$$ds = dx \,.\, \phi = \mathrm{R} \,.\, d\theta$$

where

$$\mathrm{R} = \mathrm{OG}$$

and

$$\phi = \mathrm{R}\frac{d\theta}{dx}.$$

Note that ϕ is a very small angle, and we may therefore assume that $\tan\phi = \phi$ in this case.

If p_1 is the intensity of stress at the greatest strained fibre $p_1 \propto \phi$ and hence $p_1 = \mathrm{C}\phi = \mathrm{CR}\frac{d\theta}{dx}$.

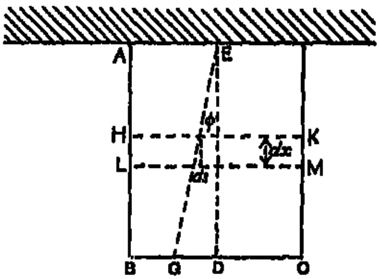


FIG. 22.

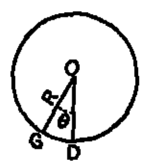


FIG 22a.

Again, since the strain, and consequently the stress, within the elastic limit varies with the distance from O, the stress at any point r along the radius OG is

$$p = p_1\frac{r}{\mathrm{R}}.$$

At the distance r the area of an elementary ring of width dr is $2\pi r \,.\, dr$, and if p is the intensity of stress acting on this area the moment about the axis O is

$$p \,.\, 2\pi r \,.\, dr \,.\, r \,. = p 2\pi r^2 dr.$$

Integrating this expression over the whole area the moment is

$$\mathrm{M} = 2\pi\int_0^{\mathrm{R}} pr^2 dr = 2\pi\frac{p_1}{\mathrm{R}}\int_0^{\mathrm{R}} r^3 dr = \frac{p_1}{\mathrm{R}}\frac{2\pi\mathrm{R}^4}{4} = \frac{p_1\pi\mathrm{R}^3}{2}$$

for a solid rod. For a pipe of internal radius R_1 the expression becomes

$$\mathrm{M} = \frac{p_1\pi(\mathrm{R}^4 - \mathrm{R}_1{}^4)}{2\mathrm{R}}.$$

Hence for a solid rod $p_1 = \frac{2M}{\pi R^3}$,

and for a tube of concentric bore

$$p_1 = \frac{2MR}{\pi(R^4 - R_1^4)}.$$

These formulæ are used in designing shafts.

It has already been shown that

$$\phi = R\frac{d\theta}{dx},$$

and

$$p_1 = C\phi.$$

If ψ is the angle of twist per unit of length along ED, we have

$$\psi = \frac{d\theta}{dx} = \frac{\phi}{R} = \frac{p_1}{CR}.$$

Inserting the value for p_1 for solid shafts found already, we have

$$\psi = \frac{2M}{C\pi R^4} \quad \text{or} \quad C = \frac{2M}{\psi\pi R^4} = \frac{32M}{\psi\pi D^4},$$

which may be written $C = \frac{32Ml}{\theta\pi D^4}$ if it be more convenient to consider the total angle of twist for length l rather than the twist per unit length. The last-named formula is generally used when determining experimentally the modulus of rigidity (C) of a wire.

The modulus of rigidity is a constant characteristic of the material for strains within the elastic limit, and serves a similar purpose in torsion calculations to that of Young's modulus (E) in tension and compression calculations. For cross-sections other than circular the formula does not hold. The general theory covering non-circular sections such as square sections was investigated by St. Venant, but a discussion of these cases is beyond the scope of this book.

For commercial testing of a routine character the foregoing description of the theory of stress and strain should prove adequate, but no claim is made that the subject has been fully dealt with, and the reader may profitably pursue the subject in such standard works as

Ewing's " Strength of Materials ; "
Unwin's " Testing of Materials of Construction ; "
Rankine's " Applied Mechanics," etc.

CHAPTER III

IRON AND STEEL

A LARGE proportion of the brown and red earths that occur in nature owe their colour to the presence of oxides of iron—iron rust is an oxide of iron—but as a rule the percentage of iron they contain is too small to admit of its being economically extracted. Oxide of iron, however, is found in large deposits as iron ore, and in this country it is frequently found in close proximity to deposits of coal and limestone, both of which are used in the smelting of iron. The principal ores that are smelted for the production of pig iron are magnetite, red hematite, brown hematite, spathic iron ore (carbonate of iron), and clay ironstone. The preliminary treatment of the ores varies in different districts. In some the ore is roasted in heaps to expel carbon dioxide, moisture, and part of the sulphur that may be present; whilst in other districts the ore is in a suitable condition to be put direct into the blast furnace. Modern blast furnaces are about 100 feet in height, and when once lit may be worked continuously for years, the fire burning all the time. The smelting process may be popularly described as follows: The ore is mixed with appropriate quantities of coke and limestone, the latter being used to extract sand (silica) and clay (aluminium silicate), which are present as impurities in the ore. The charge of ore, coke, and limestone is fed into the hopper at the top of the furnace on to an inverted cone, and the hopper cover is closed. The cone is then lowered and the charge falls into the furnace, which is already nearly full of similar material. The charge travels slowly down the furnace, and complicated chemical changes take place at various stages of its journey. A blast of hot air under several pounds pressure is forced into the furnace at a number of places near the bottom through pipes or tuyeres, and burns the coke to carbon dioxide (CO_2). This gas travels up the furnace, and in passing over incandescent coke (carbon) is reduced to carbon monoxide (CO), which in turn reduces the oxides of iron to metallic iron and reforms carbon dioxide as indicated by the following chemical equation :—

$$Fe_2O_3 + 3CO = 3CO_2 + Fe_2.$$

$$\text{(Oxide of iron) and} \begin{pmatrix}\text{Carbon}\\\text{monoxide}\end{pmatrix} \text{form} \begin{pmatrix}\text{Carbon}\\\text{dioxide}\end{pmatrix} \text{and} \begin{pmatrix}\text{Metallic}\\\text{iron}\end{pmatrix}.$$

The limestone ($CaCO_3$) is decomposed by the heat of the furnace forming lime (CaO) and carbon dioxide. The lime combines with the sand and clay, forming slag (calcium silicates and aluminates), which travels to the lower part of the furnace and floats upon the molten iron, which is the heaviest material in the furnace. The actual chemical changes are much more complicated than the foregoing description sets forth, and of course they vary with the mixture, temperature of working, etc., but the foregoing must suffice for the present purpose. The hot gases formed during the smelting process possess considerable calorific value, and they find an exit at the top of the furnace into a side flue. After heating the ovens through which the air blast passes on its way from the blowing engines to the furnace, the hot gases are purified and used in the gas engines which drive the blowers and for other purposes. The slag escapes by overflow through a plug-hole in the furnace wall a few feet above the hearth, and is caught in iron tubs and subsequently conveyed to the slag heap or tip. The molten metal is tapped off through a plug-hole at the bottom of the furnace every five or six hours, and flows along sand troughs to small sand moulds (pigs) to cool. The iron which flows in the earliest stages is the hottest and is a clear liquid; later on "flowers" form on the surface of the liquid metal due to the separation of graphitic carbon. The furnace foreman is able from his knowledge of the mixture and the appearance of the metal as it flows to select different grades of iron for his several purposes, and he diverts the white-hot stream by putting up sand barriers and opening out other channels, some going perhaps direct to a casting ladle, some for wrought iron or steel making processes, and the remainder into the pig beds.

Pig Iron is generally graded by practical men on the appearance of the fracture. This depends largely upon the rate at which the iron has cooled and the form in which the carbon is present. The carbon can be either chemically combined with the iron or present in the free or uncombined state, when it is generally referred to as graphitic carbon. When the fracture of pig iron is dark grey nearly all the carbon is present in the graphitic form, but when the fracture is white a large proportion of the carbon is present in the chemically combined form. The proportion of silicon present in pig iron also influences the state in which the carbon is present. Between the two extremes white and grey the fracture is more or less mottled with shining crystals in a grey matrix. For foundry purposes pig iron is generally graded into four numbers: No. 1 (grey), No. 2, No. 3, and No. 4 (white), whilst there is also a No. 4 (forge), which is used for the making of wrought iron. In addition to carbon pig iron contains small and varying percentages of silicon, sulphur, manganese, and phosphorus. The composition of pig iron varies within wide limits, but the following figures give a rough idea of the percentages usually found:—

Combined carbon	. . . . .	0·1 to 1·0 per cent.
Graphitic ,,	. . . . .	1·0 ,, 3·0 ,, ,,
Silicon .	. . . . .	2·0 ,, 4·0 ,, ,,
Manganese	. . . . .	0·25 ,, 2·5 ,, ,,
Sulphur	. . . . .	0·02 ,, 0·1 ,, ,,
Phosphorus	. . . . .	0·40 ,, 1·3 ,, ,,

Cast Iron.—For the casting of pipes, split couplings, junction boxes, etc., No. 3 foundry pig iron mixed with scrap cast iron is generally used. The metal is re-heated in a small blast furnace called a cupola, with appropriate quantities of limestone and coke. The re-heating under these conditions tends to liberate the combined carbon, and the resulting casting is of grey cast iron, the carbon being principally in the graphitic form, and if a fractured surface be slightly magnified the carbon can be seen as glistening plates. Ordinary grey cast iron is very brittle, and when tested in tension there is practically no elongation. The tensile strength varies

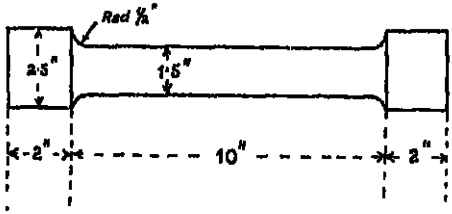


Fig. 23.

generally from 8 to 15 tons per square inch. On account of brittleness and low tensile strength, cast iron is seldom used in simple tension. The compression strength of cast iron, however, is high, and in the neighbourhood of 55 tons per square inch for cylindrical test specimens if the height of the specimen is about equal to the diameter. Beams made of cast iron are consequently designed so that there is more material on the tension side than on the compression side, so as to approximate to equal strength at all parts of the section to resist bending stresses. The testing of cast iron in tension is not very satisfactory, owing to the fact that it is almost impossible to ensure that the pull will be uniformly distributed over the area of cross-section or along the axis of the specimen. The bars for tension tests are cast in special moulds when the metal for the castings is being poured, and the shape of the test bars adopted by the Post Office is shown in Fig. 23. These bars are afterwards machined to the shape shown in Fig. 24.

The seating at B is machined to a definite radius, and the load is applied by means of a screwed split nut fitting the seating accurately and screwing into the testing machine crosshead. The smaller section at C ensures that the fracture will take place in this part, but it generally occurs close to one of the shoulders, so that even

with the precautions mentioned above the pull is probably not perfectly axial.

Cast-iron pipes for telegraph and telephone purposes differ only slightly from ordinary cast-iron pipes, the principal difference being in the width of the bead at the spigot end, which is $1\frac{1}{2}$ inches, the

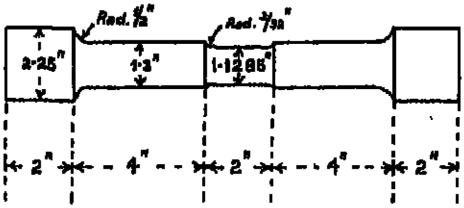


FIG. 24.

greater width being provided so that bonding bolts may be fitted to reduce the chance of electrolytic trouble. The moulding pattern is generally made of steel and machined smooth all over. Green sand is used for moulding the external surface, but dry sand is used on the core. The term "green sand" is applied by moulders to loam that is not baked before the metal is poured, and "dry sand" to loam that has to be baked after moulding and before the metal is poured. The core is supported by either a core screw or chaplet. Fig. 25 shows a sketch of a chaplet. This is placed in the top half of the mould, about half way along the mould, to give support to the core when the metal is poured, otherwise the core, although fixed at the two ends, would bend upwards, due to its tending to float on the fluid metal. This would produce a pipe having a bore eccentric with the external surface. Any want of uniformity in the thickness of the wall of the pipe renders the pipe relatively weak and liable to break after despatch by rail. Pipes occasionally show this defect, but it is readily detected by rolling the pipe along a gantry, as the pipe, if "thick and thin," travels in fits and starts and not uniformly. The chaplet remains in the wall of the pipe, and it has to be accurately fitted in the mould to ensure the correct thickness of the wall of the pipe. For telephone, etc., purposes, core screws are not looked upon favourably, because although they appear to be satisfactory for water pipes, where they probably rust tight, it is found that for telephone purposes they are liable to work loose and project, and consequently would damage lead-covered cables when being drawn in. The core, which is fixed in the mould at the two ends and which determines the shape of the interior of the pipe, is usually built up on an iron tube with vent holes at various places along its length.

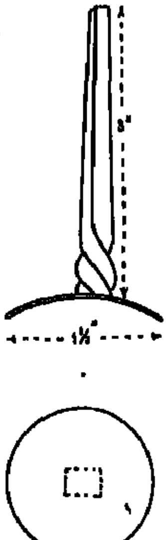


FIG. 25.

A layer of hay bands is first wound on the tube, and then wet loam is worked over the hay bands and the surface brought to the exact shape of the interior of the pipe by rotating the core against a profiled board. The core is baked for about twenty-four hours to make it dry and hard, and it is then cleaned up for use in the mould. After the core has been fitted in the mould the mould is placed on the casting bank, which slopes at an angle of about 36° with the horizontal, and the metal is run in from the casting ladle. At some of the larger ironworks the pipes are cast in a vertical position, which obviates the need for a chaplet or core screw, but the spigot is chilled by the iron plate at the bottom of the mould, and special care has to be taken to ensure that the chilled part is confined to about ¼ inch of the end of the spigot, or trouble will be experienced in drilling the spigot bead for the bonding bolt when the pipes are brought into use. After the metal has set and cooled sufficiently, the pipes are taken out of the mould, the end of the chaplet tang hammered over where necessary, and the pipe is cleaned or fettled, as it is termed. They are subsequently well heated to about 200° F. and then coated with a bituminous compound, the composition of which varies with practically every foundry. The compound specified by the Post Office is Dr. Angus Smith's, consisting of

Coal tar	1 cwt.
Tallow	7 lbs.
Quicklime (slaked)	10 ,,
Pine resin	4 ,,

Coal tar naphtha sufficient to thin the compound to a degree suitable for proper coating.

In the coating of pipes it is important to see that they are clean and free from casting sand, otherwise the compound does not adhere to the iron satisfactorily. The pipes begin to rust at places where sand is left on, and the rust subsequently travels along under the compound until the whole surface of the pipe is covered with rust and the compound flakes off. Where pipes have to be stored at the maker's works for a long time, it is important to see that they are evenly coated all over if rusting is to be prevented. After cleaning the pipes some makers heat the pipes in boiling water before coating them with compound. This process ensures that they are quite free from casting sand and the liability to rusting is reduced. Compounds of a bituminous character are the best preservatives for cast iron, as they prevent electrolytic action along the surface of the pipe, which is one of the causes of rusting. It has been proved that if two parts of the same piece of metal are of different degrees of hardness, there is an electrical potential difference between them, and if a conducting path such as moisture be provided electrolytic action takes place slowly. Another principal cause of rusting, however, is the chemical one brought about by the oxygen of the air in the presence of moisture and carbon

dioxide, both of which occur plentifully in the neighbourhood of any large foundry. Here again the bituminous compound is an effective preservative, owing to its chemical inertness. As telephone pipes are required for accommodating costly lead-covered cables, it is important to see that they are of the specified internal diameter, and that the inside surface is quite free from sharp edges and projections. The diameter is checked by passing a steel disc through the pipe. For working purposes the disc is usually 20 mils larger than the specified minimum diameter, so as to provide a margin for wear, but in the event of a pipe being too small to take this working disc, a steel disc of the exact diameter is tried, and the pipe approved if it will take this. Fig. 26 shows the standard disc, which is backed off so that the effective diameter of the disc will not be appreciably increased if the disc is not quite square when pushed into the pipe. The disc is fitted to a 10-feet wrought-iron bar when being used. Where chaplets or core screws are used, they are liable to cause projections, and it is necessary to pay particular attention to that part of the pipe where the core screw or chaplet is located. A board painted white or a sheet of white cardboard held at one end of the pipe in a slanting direction will deflect sufficient light into the pipe to enable any roughness and projections to be readily seen from the other end.

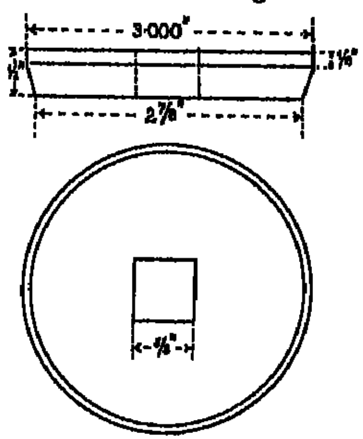


FIG. 26.

The shoulder of the socket is occasionally rough on the inside. This can be most easily detected by putting the hand in the pipe and feeling for rough places. A thick leather glove is usually worn whilst examining pipes. The pipes should be straight and roll evenly, but anything up to ¼-inch dip in 9-feet pipes, or ⅛-inch dip in 6-feet pipes, is generally accepted as satisfactory. Two-inch pipes cannot, as a rule, be made in longer lengths than 6 feet, when chaplets or core screws are used, owing to the tendency of the thin core to bend. Most makers subject the pipes to a hydraulic pressure test before coating to detect any imperfections such as blow-holes, splits, etc. Cementing up defective places with moulder's cement is generally prohibited, and only occurs when the moulders are able to evade the vigilance of the foundry foreman, but it is as well to look out for these places during inspection, otherwise trouble from rough places may develop, due to the cement becoming loose after the pipe is laid. The "lay" of a pipe is less than its total length, and is generally taken at the round figure of 9 feet for 3-inch, 3½-inch, and 4-inch pipes, whilst the overall length is 9 feet 4 inches, and for 2-inch pipes 6 feet and 6 feet 4 inches

respectively. Cast-iron telephone pipes are not expected to act as girders, but when tested as girders they give results of the following order :—

LOAD APPLIED IN MIDDLE OF SPAN

Nominal Size, Inches.	External Diameter, Inches.	Thickness of Wall, Mils.	Temporary Deflection, Inch at cwts.	Breaking Load, Cwts.	Distance between Supports, Feet.	Value of C calculated on Minimum Thickness.
2	$2\frac{11}{16}$	290-335	$\frac{1}{16}$ at 20	20·5	5	21·6
2	$2\frac{11}{16}$	265-330	$\frac{1}{16}$ at 20	20·0	5	22·6
2	$2\frac{11}{16}$	230-305	$\frac{1}{8}$ at 16	18·0	5	22·3
3	$3\frac{3}{4}$	285-325	Not measured	30·0	8	23·9
3	$3\frac{11}{16}$	275-410	$\frac{3}{8}$ at 28	29·0	8	23·0
3	$3\frac{13}{16}$	275-365	$\frac{1}{8}$ at 24	27·0	8	21·4
3	$3\frac{5}{8}$	315-340	$\frac{1}{4}$ at 31	36·0	8	24·8
$3\frac{1}{2}$	$4\frac{1}{16}$	325-365	$\frac{1}{4}$ at 34	36·0	8	21·7
$3\frac{1}{2}$	$4\frac{1}{8}$	290-430	$\frac{1}{8}$ at 28	30·0	8	19·1
4	$4\frac{3}{4}$	340-390	$\frac{1}{16}$ at 52	56·5	8	23·3
					Average	22·4

The value of C was calculated from the formulæ deduced in Chapter II, namely :—

$$M = \frac{WL}{4} = CZ = \frac{\pi C(R^4 - r^4)}{4R}. \qquad \therefore C = \frac{WLR}{\pi(R^4 - r^4)}$$

where L is in feet, R and r in inches, and W in cwts.

Joint Boxes.—Chipping fillets are cast on the bodies to provide means for adjusting the fit of the covers, so as to prevent tilting. It is advisable to mark the cover and body with a distinctive paint mark or number indicating the position in which the fit has been obtained, so that they can be put together readily in the correct position. Covers cannot economically be made to fit satisfactorily in more than one position, but it is important that they should fit in one position, otherwise complaints from road authorities will be received, drawing attention to the rock or shake of the cover when stepped on by pedestrians, and calling for immediate adjustment, which is not an easy matter when once the box is laid. The boxes are coated with a similar composition to that used for pipes. If wood patterns are supplied to the founder they should allow for double contraction, so that iron patterns can be cast from the wood patterns. The usual allowance for shrinkage in single contraction is $\frac{1}{8}$ inch per foot, and other dimensions in proportion. The finished castings should be sound and clean. If blow-holes are suspected, a light tap with a hammer or a centre punch will show up the defect if it exists. Any lettering or studs should be level with the frame and cover, so as to avoid ridges or projections likely to trip up pedestrians. A minimum weight is usually stipulated for castings. A cubic foot of cast iron weighs 450 lbs.

Malleable Castings are generally made from a special grade of white cast iron rich in silicon. Saddles used on the top of telegraph poles are made of malleable cast iron. After casting they are put into iron boxes and surrounded with rich oxides of iron such as red hematite and hammer scale in small pieces somewhat smaller than peas. The boxes are then put into an annealing furnace usually gas fired—because the temperature is thereby more readily controlled—and raised and kept at a red heat for several hours. The oxides of iron react with the carbon in the cast iron, and at the end of the process very little of the carbon is found to be combined with the iron. The resulting casting is rendered by this process both tough and soft, and the two straps of the saddle, if the process has been effectively carried out, will stand bending through a right angle of fairly sharp radius without breaking or showing signs of cracking.

Wrought Iron is made by the puddling process, and is practi-

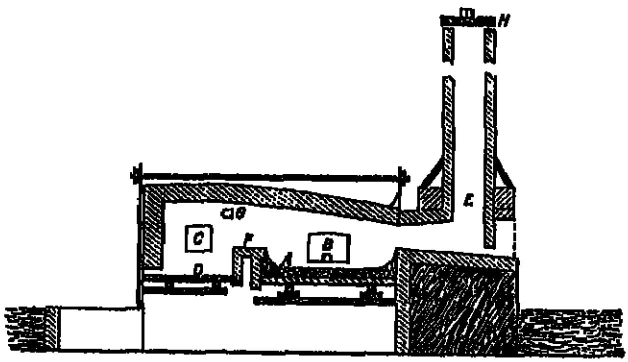


FIG. 27.—Puddling furnace, vertical section (from Stansbie's "Iron and Steel," Constable & Co.).

A = Working bed. B = Working door. C = Firing door. D = Grate.
E = Chimney. F = Fire-bridge. G = Staff-hole. H = Damper.

cally pure iron. The quality of wrought iron depends very largely upon the quality of the pig iron from which it is made, and for ordinary grades of wrought iron a blend of several grades of pig iron is frequently used. The puddler may be quite unaware of the different grades of pig iron which go into one heat, as the pig iron is stacked in layers by the side of the furnace, and each layer is enough for one heat, and may consist of three or four different grades of pig iron. The quality of the pig iron is judged by the foreman from an examination of a fracture, and his knowledge of the source of the iron and the arrangement and blending of the stacks at each furnace are his special function. The roof of the furnace slopes downwards from the fire side to the flue, so that the flame is thrown down towards the hearth on which the pig is worked. The puddler works through a hole in the side of the furnace. The hearth and sides of the furnace are lined or fettled, as it is termed in Staffordshire, with

rich oxides of iron. The latter are obtained as by-products of the several processes in the form of hammer scale, roasted tap cinder, etc. The furnace is charged with about 5 cwt. of pig iron and heated for about ten minutes, when the puddler rearranges the charge so that the heating is as uniform as possible throughout the bulk. In about half an hour the pig iron begins to melt freely, and the metallic iron sinks to the bottom, leaving silicates and oxides of iron floating. The melted iron is raddled or stirred up with long wrought-iron rods until all is thoroughly liquid. The fire is under control by means of dampers in the flues, and can be regulated so as to produce a smoky (reducing) flame or a clear (oxidizing) flame, and it is the management of these dampers by the puddler that requires experience and judgment. When the iron is thoroughly liquid the damper in the flue is nearly closed, and a reducing or smoky flame is caused to play on the top of the metal, reducing the oxides and burning off part of the carbon. As soon as the carbon has been sufficiently decreased the damper is again opened, and the stage known as boiling begins. During this stage the silicon and other constituents of the cinder are worked over the front plate and caught in an iron pot for subsequent treatment as a by-product. Then the pure iron begins to form in small lumps and to coalesce into a loose mass somewhat resembling white-hot clinker. If a sample of the iron is cooled rapidly by dropping into cold water at this stage it has a purple appearance, owing to the sulphur which is present as sulphide of iron. After the sulphur has been oxidised and driven off, the iron is worked into four or five balls by the puddler. These are taken to a steam hammer to be hammered or shingled into a shape suitable for the first rolling process. The ball is generally from 90 to 100 lbs. in weight, and after a few blows with the steam hammer, which squeezes out the more fluid cinder, the ball is hammered into a rectangular bloom. The condition of the cinder which is squeezed from the bloom during the hammering is some indication of the quality of the iron, the more viscous the cinder the better the iron. The melting-point of pure iron is much higher than that of pig iron, and it is on this account that during the puddling or purifying process the small lumps of pure iron solidify out of the liquid. Poor iron, therefore, will not show a viscous cinder, because the impurities that are present lower the melting-point of the cinder and keep it fluid. The rectangular bloom, whilst still hot, is passed through a series of grooved rolls (each groove smaller than the one preceding), until it is about 10 feet long and $2\frac{1}{8} \times \frac{7}{8}$ inches in section, and is then allowed to cool. If the iron is nicked with a chisel and bent over at this stage, the fracture shows a coarse fibre, due to the crystal grains of iron being elongated by the rolling and the drawing out of the imprisoned cinder and graphite, which are still present in appreciable quantity. The subsequent treatment will depend upon the use for which the wrought iron is required. For example, high-grade Staffordshire iron is treated as follows: the 10 feet bar is cut up into lengths of

10 inches and piled in layers of four lengths side by side, the adjacent layers being at right angles to each other until the pile is about 9 inches high and 10 inches square. The pile is strapped together with iron wire and re-heated in a ball furnace somewhat similar to a puddling furnace, but capable of being heated to a higher temperature, and the lining is not fettled with oxides of iron. The pile, after heating to a cherry red, is again shingled under the steam hammer, which squeezes out a further quantity of the impurities in the form of cinder, and after being worked into a rectangular bloom the iron is again rolled to a 10 feet bar as before and allowed to cool. If the bar is nicked and bent over at this stage the fracture may appear crystalline because the iron is nearly free from cinder, and the rolling process has not been carried far enough. The iron is what is known in the rolling mill as *young*, and will bear re-heating and rolling several times without danger of being rendered brittle. Ball-furnaced iron wire is regarded as the best and most durable wire for the sheathing of submarine cable, its life being stated to be much longer than that of Bessemer or other mild steel wire. Rods and wire obtained from ball-furnaced iron show a characteristic fibrous fracture, and the difference between the physical properties of wrought iron and cast iron is very marked. Good wrought iron is very tough and fibrous when broken by nicking and bending over—it is important to note that on the compression side of a fracture it will of necessity be crystalline in appearance—but cast iron is short and brittle, and the fracture is always crystalline. If, however, wrought iron is burnt or overworked it will lose its toughness and fibrous character and become very similar in appearance and physical properties to cast iron. In Staffordshire the quality of bar iron is referred to as *Best*, *Best Best*, and *Best Best Best*, and in the early days of manufacture the terms referred to the processes through which the iron had passed, but with more scientific control at the puddling stage, and the more expert knowledge of the composition of the pig iron used in manufacture, the terms no longer bear this signification, the quality depending largely upon the quality of the pig iron. Especially is this the case in Yorkshire (Lowmoor) irons, which are obtained from high-grade pig irons purified by special methods.

Wrought-Iron Bolts.—All the bolts, except insulator bolts, used on pole lines are made of wrought iron, and are galvanised with zinc spelter. It is characteristic of wrought iron that if it be nicked with a chisel to about one-fifth of its section and then bent through an appreciable angle by hammering, the surface disclosed has a fibrous appearance, and the fracture also is fibrous in appearance if the iron be of good quality. In the case of bolts the iron may be of good quality but be spoilt by overheating when the head is being forged. In examining bolts it is advisable to nick the bolt with a chisel to about one-fifth of its diameter at about $\frac{1}{2}$ inch from the head and bend it over by hammering the head. If the iron has been spoilt by overheating the metal will show a fracture of crystals and

will have lost all its toughness, the metal breaking short at the nick after one or two blows with the hammer. The same bolt tested well away from the head may prove to be of quite satisfactory quality. Since telegraph arms, etc., are held, as a rule, by only one bolt, it is important to obtain bolts which are as far as possible free from defects of this kind. A burnt head will stand a good deal of hammering, and will appear to be fairly soft while the metal is being compressed, but the metal is very weak in tension, and as the bolt is used in tension it is advisable when testing bolts to use the nicking and bending test rather than to hammer the head, a method which is sometimes used. In the Post Office specification it is stipulated that "The heads when supported on the under side shall not fail when a pull is applied to the bolt sufficient to break it at its full section." For bolts used on pole lines "Best Best" Staffordshire iron is specified, and the minimum requirements for iron of this quality are:

Breaking load	23 tons per square inch.
Elongation on 8 inches . .	20 per cent.
Reduction in area . . .	30 per cent.

The bolts are screwed to Whitworth's standard. As the screw thread is cut after the bolt is galvanised, it is specified that the thread shall be treated with a good heavy oil to prevent rusting. The nuts should be a reasonably good fit and free from large burrs that would prevent their bedding satisfactorily on the washers. The washers should be free from cracks. The weakest part of the bolt is the screw thread, and when the bolt is tested by pulling against the head and nut, the fracture takes place in the screw thread. The elongation of a bolt tested in this way is very small, because the plastic stage is reached at the smaller area of the screw thread before the remainder of the bolt reaches its elastic limit, and consequently the permanent set is confined to a very short section of the bolt. The 20 per cent. elongation referred to above applies only to the unscrewed portion of the bolt, which before test is turned down to an even diameter, the galvanising being completely removed.

Galvanised Iron Stay Rods and Stay Tighteners.—There are three sizes used by the Post Office, viz., for $\frac{5}{8}$ inch, $\frac{3}{4}$ inch, and 1 inch stay rods. The crosshead of the stay tighteners is a casting of best hematite iron, and when tested with a steel bolt the minimum transverse breaking load of the crossheads should be $7\frac{1}{2}$ tons, 11 tons, and 17 tons respectively. The stay rods and bows are made of Best Best Staffordshire iron, and when tested should comply with the requirements for the other bolts used on pole lines given above.

Galvanised Iron Stay Swivels.—There are two sizes used, viz., $\frac{1}{2}$ inch and $\frac{5}{8}$ inch, the specified minimum breaking load when tested complete from eye to eye being 2·8 tons and 4 tons 15 cwt. 1 qr. 23 lbs. respectively. The complete swivels are made of Best Best Staffordshire iron throughout.

Steel.—One of the principal differences between cast and wrought iron on the one hand, and all ordinary types of steel on the other, is that in cast iron and wrought iron there is always a certain amount of free or graphitic carbon, whilst in steel the carbon is all combined with the iron. If about 0·2 gramme of drillings from any of these materials be dissolved in a few cubic centimetres—say 4 or 5—of nitric acid of 1·2 specific gravity, the solution will be brown in colour, and the depth of colour will be proportional to the amount of combined carbon present in the materials. In the case of steel the solution is complete and quite clear, but with cast iron and wrought iron there is always a small portion that will not dissolve consisting of black graphitic carbon. The percentage of combined carbon in steel can be ascertained quantitatively by means of this colour test if suitable precautions with regard to the standard steel, which provides a comparative colour, are taken. The test is known as the Eggertz tube test, and is fully described in Arnold's "Steel Works Analysis," where the necessary precautions with regard to the standard are set forth in detail. The test takes only a little over half an hour to carry out, and is remarkably accurate under proper conditions, but when these conditions cannot be met the carbon should be estimated by the usual combustion method. From an inspection point of view, the nitric acid test is of value when it is desired to ascertain whether the material is of mild steel or wrought iron, the former giving a clear and complete solution, whereas the latter always leaves a residue of graphitic carbon. With small rods and wires it is often difficult to say from the appearance of the fracture whether the material is a very mild steel or a good wrought iron, and the nitric acid test can then be resorted to.

The properties of steel depend to a large extent on the percentage of carbon combined with the iron. The following table of actual tests gives a rough idea of the way the properties vary with the change in combined carbon of ordinary rolled steel, without any special hardening or heat treatment:—

Combined Carbon. Per Cent.	Breaking Load. Tons per Square Inch.	Extension on 10 Inches per Cent.	Reduction in Area per Cent.
0·11	25·9	25	60
0·25	41·5	22	55
0·27	36·9	22	40
0·42	48·2	26	46
0·69	42·7	10	21
0·80	66·0	9	6
1·01	69·4	7·5	17

When the combined carbon in steel is less than 0·10 per cent. the steel is generally remarkably ductile and soft. This steel was at one time known as homogeneous iron, but as it is produced by a steel making process, contains no free or uncombined carbon, and

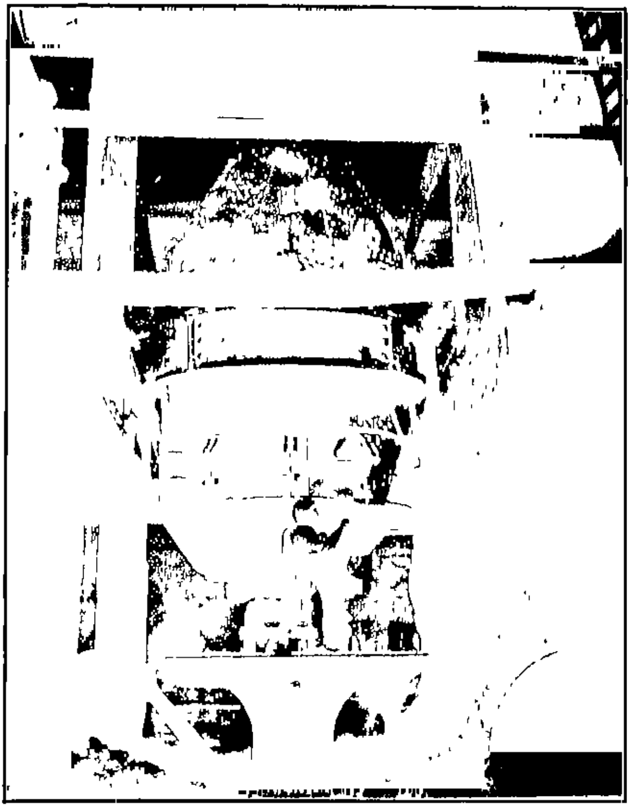


FIG. 28.—Bessemer Converter.

(From Stansbie's "Iron and Steel." Constable & Co., Ltd.)

in the process of manufacture it is actually melted, whereas wrought iron in the puddling process never, as such, really melts, there are grounds for regarding it as steel and not as iron. If the combined carbon be from ·15 to ·25 per cent., the steel is usually referred to as mild steel, 0·4 per cent. is a rail steel, 0·6 per cent. spring steel, 0·8 and above tool steel. Steels containing up to about 0·5 per cent. of combined carbon are generally made by one of two processes, namely, the Bessemer or the Open Hearth. Both of these may be either *basic* or *acid*. The terms basic and acid are derived from the material used in lining the furnaces, it being necessary to employ a basic lining when the pig iron from which the steel is made contains an appreciable percentage of phosphorus. The basic material will combine with, and thus eliminate, the phosphorus. The basic material is dolomite lime. Dolomite is found native, and consists of calcium and magnesium carbonates in approximately equal parts. The dolomite is calcined forming dolomite lime, which is used to line the furnace. Part of the lining combines with the phosphorus and goes into the slag, which floats on the molten metal, and is tapped off at the end of the steel making process. Phosphorus makes steel brittle when worked cold, but the *basic* process is so well controlled that no appreciable amount of phosphorus gets into *basic* steel. In the *acid* process the furnace is lined with *Gannister*, which is mainly silica (sand) with a little clay, and this lining will not remove all the phosphorus if it be present in appreciable quantity. It is necessary, therefore, to use pig iron practically free from phosphorus when steel is made by the acid process.

In the Bessemer process molten pig iron is poured into a Bessemer converter (Fig. 28), and a blast of air is forced through the metal, oxidising the carbon to carbon monoxide, which burns at the top of the charge. In this way all the carbon, if desired, can be eliminated but part of the iron becomes oxidised, and it is necessary to reduce this oxide by adding compounds containing manganese in the form of either ferro-manganese or a manganiferous pig iron, otherwise this oxide would cause the steel to be unworkable and have properties similar to burnt steel. The carbon necessary to produce the grade of steel required is added specially, and the amount is consequently under complete control. The converter is mounted on trunnions, so that at the end of the process it can be tilted and the charge poured into a casting ladle.

In the Open Hearth or Siemens-Martin process a furnace somewhat similar to a puddling furnace is used, but it is worked on the regenerative principle, so that the incoming flame is alternately on the right and left of the hearth, and the hot flue gases heat the incoming air and producer gas, which is used as fuel. The charge, consisting of pig iron and scrap iron, is put in cold, but as quickly as possible, and the heating commenced, the air and gas being reversed in direction periodically—about every twenty minutes—until the charge is quite molten. High-grade oxide of iron in the form of hematite ore is then added, and causes the molten iron to

boil up, due to the oxygen from the ore burning the carbon to carbon monoxide. When the carbon has been eliminated, ferromanganese is added, as in the Bessemer process, and the metal is run into the casting ladle, the necessary amount of carbon being added while the metal is being run.

Steel containing more than 0·5 per cent. of carbon is generally made by the cementation process, which is carried out by heating bars of high-grade wrought iron in contact with finely divided charcoal. The bars are usually about 12″ × 3″ × ⅝″, and they are piled in layers in firebrick boxes, each bar completely surrounded and in intimate contact with charcoal. The top of the box is protected from the furnace gases by means of a layer of oxide of iron. The heating is continued for several days, the charcoal diffusing through the metal, the amount of carbon combining with the metal depending upon the temperature of the furnace and the length of time the heating is continued. The amount of combined carbon can be ascertained from time to time by means of a trial bar, which can be extracted conveniently from the box, tested, and replaced. The bars when withdrawn at the end of the process have a blistered appearance, and are known as blister bars. They are cut into short lengths, piled as in ball-furnaced iron (see p. 32), re-heated, hammered, and rolled into bars. These bars are single shear steel. The piling and reheating may be repeated if bars of special quality are required, and they are then known as double shear steel.

Cast steel of the best quality is made by melting blister steel in a crucible in a coke-fired furnace. The crucible is first heated, and the charge of blister steel in small pieces is put in and a cover put on. The heating is continued until the whole melts, and the metal is then cast in iron moulds of tapering square section. Carbon is added during the process. *Crucible cast steel* generally contains from 0·8 to 1·5 per cent. of combined carbon, depending upon the purpose for which the steel is required.

Case hardening is an application of the cementation process to mild steel, but instead of wood charcoal special mixtures are sometimes used containing yellow prussiate of potash, or compounds which yield cyanogen (C_2N_2) when strongly heated. The process must be carried out under regulated conditions as regards time and temperature if satisfactory results are to be obtained. The process can be stopped at any stage, and if a sample bar be broken the thickness of the cemented shell can be readily seen, so that the case hardening can be carried to any depth desired. The cemented metal, while still at a good red heat, is plunged into cold water, which imparts great hardness to the outside shell of cemented steel. The mild steel does not blister during the process.

The methods used in hardening and tempering crucible cast steel, in the manufacture of cutting tools, have been greatly improved in recent years by the information yielded by microscopical examination of polished and etched specimens which had been hardened and tempered under scientific conditions as regards temperature and

rate of cooling. The following terms are used by metallurgists to distinguish the constituents that the microscope reveals :—

Ferrite is pure iron.

Cementite is a chemical compound of iron and carbon (Fe_3C), containing approximately 6·67 per cent. of carbon.

Pearlite consists of alternate layers of cementite and ferrite, and owes its name to its appearance under the microscope, the layers being very minute, curved, and pearly. Steel containing 0·9 per cent. of carbon, when suitably annealed, consists mainly of pearlite.

Martensite or hardenite has practically the same chemical composition as pearlite, but is produced by a different heat treatment. It is regarded as a solid solution of carbon in iron.

Austenite is a constituent of the higher carbon steels and is softer than martensite.

The influence of some of these constituents in causing steel to corrode is of considerable interest, and Dr. W. H. Hatfield, in a recent work published by Messrs. Thos. Firth & Sons, Ltd., Sheffield, on "The Development of Stainless Steel," in discussing the general subject of corrosion, says: "It has been shown that in steel the varying constituents ferrite, pearlite, cementite, solid solution, all possess different electric potentials, and that these differences are well defined. Hence if a steel contains two or more of these constituents, we get selective corrosion—the cementite or carbide present is kathodic to the other constituents, hence we get corrosion starting in the pearlite or solid solution areas; these are eaten away while the carbide remains outstanding and unattacked. It would appear that in all cases the carbide acts as the kathode, and is only removed by disintegration of the mass due to the corrosion of the other areas. This is well demonstrated by the fact that in most etching solutions the carbide remains as a white mass, i.e. is unattacked while the remainder is blackened, i.e. corroded." The foregoing facts may account for the greater durability of ball-furnace iron referred to on page 32 as compared with Bessemer or other mild steel wire.

Steel used for making tools seldom contains less than 0·5 per cent. of combined carbon as steels containing lower percentages than this cannot be hardened sufficiently for ordinary purposes. The higher the percentage of carbon the harder and more brittle the steel becomes when suddenly cooled after being raised to a red heat. For most purposes steels have to be tempered after being hardened, so as to reduce the brittleness caused by the hardening process. The hardened steel is reheated to a temperature of 200° to 300° C., and the higher the tempering temperature within these limits the more the brittleness is decreased. On a polished or bright surface of the steel the colour of the film of oxide which forms as the temperature rises, is a rough guide to the temperature actually reached. Hardenite is formed in the hardening process and in the tempering process part of the hardenite undergoes a structural change whereby cementite is formed. The higher the tempering

heat is carried within the above limits the greater is the proportion of cementite formed, and consequently the softer and tougher the steel becomes. The following table, which is taken from Stansbie's "Iron and Steel," shows the relation between tempering colour and temperature :—

Colour.	Temperature.	Suitable for—
Faint yellow	220° C.	Surgical knives.
Straw "	230° C.	Razors, taps, dies.
Brown "	255° C.	Scissors, shears.
Purple-brown	265° C	Axes, planes.
Purple	275° C.	Table knives, punches, chisels.
Light blue	288° C.	Swords, coiled springs.
Dark "	293° C.	Fine saws, augers.
Nearly black	316° C.	Hand saws.

When the desired colour is reached the tool is quenched.

Although an expert mechanic is able to get a fair idea of the hardness of a piece of steel by trying it with a smooth file, it is now usual in large works and testing houses to employ either the Brinell hardness testing machine or the Shore scleroscope for determining the hardness of steel. The latter is used by the Post Office, and is shown in Fig. 29.

At the top of a glass tube is a miniature tup hammer, which is released when the india-rubber bulb is compressed. The hammer falls down the tube on to the steel under test. It makes a permanent impression on the steel and rebounds up the tube to a height depending upon the hardness of the steel under test. The glass tube is graduated into 140 divisions. Annealed mild steel (carbon, 0·15 per cent.) will give a reading of about twenty-two divisions, whereas hardened tool steel will give about 110 divisions. The tup hammer is restored to its original position at the top of the tube on again compressing the india-rubber bulb. The instrument can be used for testing the hardness of any material, but is most largely used for testing metals.

The steels dealt with in the foregoing pages are ordinary carbon steels. There are, in addition, special steels used for cutting at high speeds, etc., and containing varying percentages of vanadium, chromium, molybdenum, etc., but a description of these is beyond the range of this book.

Insulator spindles and insulator cupholders are made from steel containing about 0·4 per cent. of combined carbon. They are tested under approximately practical conditions, the load being applied at the groove of an insulator or its equivalent, a square section india-rubber washer being fitted on the top of the spindle collar to provide a firm fit for the insulator. The Post Office specifications stipulate that the permanent set of the test sample shall not exceed the figure given in the following table at the load mentioned :—

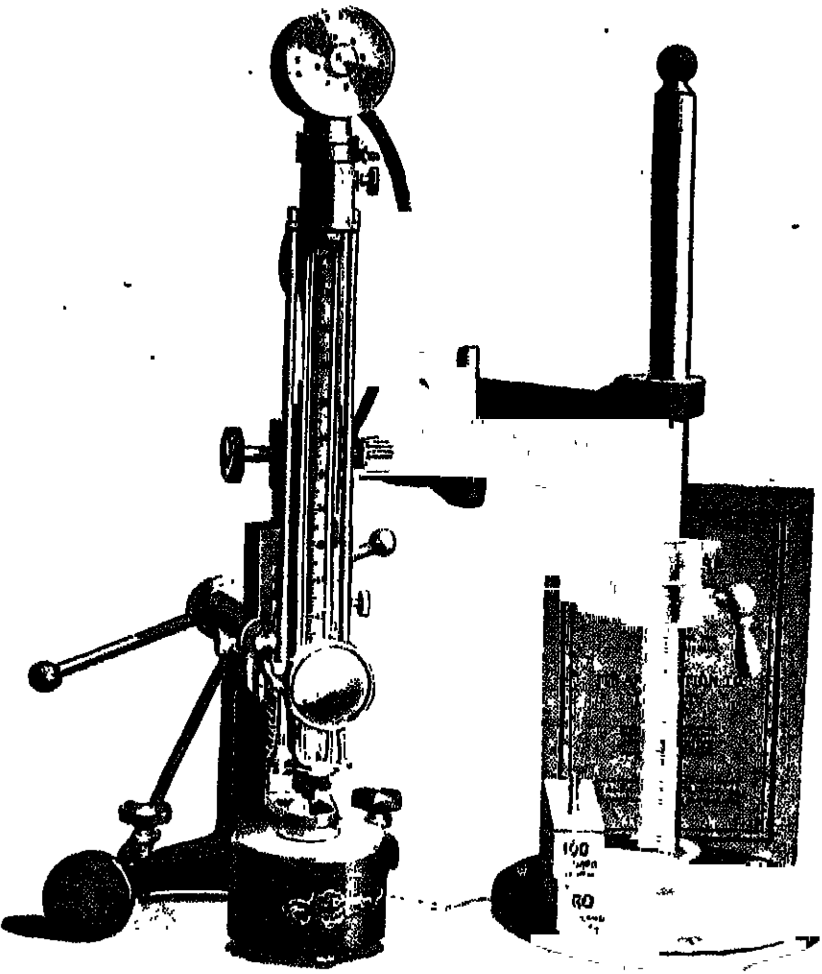


FIG. 29.—Shore Scleroscope.

(From Allcut's "Engineering Inspection." George Routledge & Sons, Ltd.)

Type.	Permanent Set at	
	784 lbs.	1680 lbs.
Insulator spindle, No. 5	1/8 in.	1 1/8 in.
" " " 13	1/8 "	1 1/4 "
Cupholders, J double 8 in.	1/8 "	1 1/4 "
" double, 8 in.	1/8 "	1 1/4 "
" quadruple, 8 in.	1/8 "	1 1/4 "

The spindles and cupholders are galvanised with zinc spelter before the screw threads are cut. The insulator screw thread has six threads to the inch, but the thread, although somewhat similar to Whitworth, is not of Whitworth's standard angle, the thread being cut to fit special gauges which are made by Messrs. Bullers, Ltd., Tipton, Staffordshire. The insulator screw thread should be well coated with black varnish put on by means of a brush (not dipped). The screw thread on the lower part of the spindle is an ordinary Whitworth, and should be well oiled before the nut is put on.

Magnet Steel.—The composition of magnet steel for telephone apparatus is not rigidly specified by the Post Office, the efficiency of the steel being taken care of in the specified performance tests of the various types of apparatus. The following analyses of permanent magnets for bell receivers give an idea of the range of mixtures used by various telephone manufacturers :—

Combined Carbon. Per Cent.	Tungsten. Per Cent.	Silicon. Per Cent.	Sulphur. Per Cent.	Phosphorus. Per Cent.	Manganese. Per Cent.	Iron. Per Cent.
0·41	7·32	0·21	0·07	0·03	0·20	Not estimated.
0·42	5·72	0·36	0·06	0·04	0·12	" "
0·33	3·40	0·20	0·08	0·03	0·38	95·4
0·42	6·16	0·12	0·07	0·02	0·18	Not estimated.
0·27	5·34	0·12	0·07	0·04	0·21	" "

Galvanised Wire.—In the early days of telegraphy large quantities of iron wire were used as line conductors, and it was generally of very high quality, being made from high-grade ore, smelted with charcoal by a cold blast process (instead of with coke and hot blast) and then puddled, rolled, and drawn. It was known as charcoal iron wire. It has not been used by the Post Office for many years, because copper and bronze possess obvious advantages, and consequently iron wire is now relegated to unimportant services ; in fact, a low carbon steel wire generally suffices for these requirements. This wire is galvanised with zinc spelter, and the coating should be capable of standing the following test : Samples from any coil after cleaning and drying are plunged into a neutral saturated solution of copper sulphate at 60° F., allowed to remain in the solution

for one minute, and are then withdrawn and wiped clean. This operation is performed four times on the same sample in the case of wire weighing 80 lbs. or over per mile, and twice in the case of Binding Wire (60 lbs. per mile), and the coating of zinc should admit of these immersions being made without showing a reddish deposit of metallic copper on the wire *after it has been wiped*. As a further test of the galvanising samples taken from any coil should bear, without the zinc showing signs of cracking or peeling off, bending round a bar,

$\frac{1}{4}$	in.	in diameter	for binding wire, 60 lbs. per mile.
$\frac{1}{2}$	,,	,,	line ,, ,, ,,
$\frac{3}{4}$	,,	,,	No. 14 S.W.G.
1	,,	,,	,, 12 ,,
$1\frac{1}{4}$	,,	,,	line wire, 200 lbs. per mile.
$1\frac{1}{2}$	,,	,,	,, 400 ,, ,,
2	,,	,,	No. 8 S.W.G.

Torsion Tests.—As a proof of quality the galvanised wire should bear without breaking or showing signs of splitting, or any other defect, the number of twists set down in the following tables for the respective types of wire. The tests are made as follows: The wire is gripped by two vices, one at each end of the length of wire shown in the tables, and one vice is made to rotate at a speed not exceeding one revolution per second. The rotating vice is attached to a spindle and hand wheel. The bearing for the spindle is shorter than the spindle, so that the rotating vice is allowed to accommodate itself to the wire in order that no tensile stress may be applied to the specimen while under torsion. The torsion is shown by a thick ink mark along the wire, which forms a spiral on the wire during the test. The full number of twists specified should be distinctly visible between the two vices. Fractions of a turn are not taken into account.

Tensile strength is tested by means of a lever machine or other approved type. The weight on the lever is set at nine-tenths of the minimum breaking load shown in the table for the size under test. The wire has to lift this load, and the remaining load is added whilst the lever is kept continuously balanced, till the wire breaks. The load should be applied at such a rate that the test will take about twenty-five seconds, the last one-tenth of the load being applied in about five seconds. It is necessary to apply the load at an approximately definite rate, because an abnormally slow rate of loading will result in the wire breaking at a lower load, and an abnormally quick rate at a higher load, than that at the rate mentioned above.

Resistance.—The electrical resistance of line wire is measured at or calculated to a temperature of 60° F. For Post Office requirements the length of the test-piece is one-thirtieth of a mile. The weight per mile—calculated from the weight of the test-piece—

multiplied by the resistance per mile at 60° F., must not exceed the constant 5328 for ordinary line wire and 4735 for charcoal iron wire.

Stretch.—The minimum stretch per cent. is the percentage elongation measured after fracture that takes place in a length of 10 inches.

The following British Standard Specifications, Nos. 182, 183, and 184, together with the Specifications Nos. 174 to 181 inclusive, which will be found at the end of Chapter V on copper, were originally drafted by a sub-committee of which the author was chairman. This sub-committee was appointed by a Government Interdepartmental Committee representing the Admiralty, War Office, India Office, Air Ministry, Post Office, Office of Works, and the Crown Agents for the Colonies, and the specifications enumerated above, after approval by the Interdepartmental Committee, were subsequently adopted after slight amendment by the British Engineering Standards Association's Committee on Telegraphs and Telephones. They are published together in one cover by the Association, and can be obtained from the offices of the Association, 28 Victoria Street, London, S.W. 1, price 1/- net. They are printed in this book by permission of the Secretary of the British Engineering Standards Association.

No. 182—1923

BRITISH STANDARD SPECIFICATION FOR GALVANISED LINE WIRE FOR TELEGRAPH AND TELEPHONE PURPOSES

DEFINITIONS

Definition of Piece

1. The term "piece" shall denote a single length of wire without joint or splice of any description either before being drawn or in the finished wire.

Definition of Coil

2. The term "coil" shall denote one piece of wire in the form of a coil.

Definition of Bundle

3. The term "bundle" shall denote two or more coils properly bound together.

Definition of Parcel

4. The term "parcel" shall denote any quantity of finished wire presented for examination and test at any one time.

Definition of Test-sample

5. The term "test-sample" shall denote a sample taken for test in accordance with the Specification.

MANUFACTURE

Material

6. The wire shall be a low carbon steel containing approximately 0·08 per cent. of combined carbon, and shall be galvanised with virgin spelter.

Dimensions

7. The wire shall be drawn in continuous pieces of the respective weights and diameters given in the Table.

Every piece may be tested for diameter in any part without cutting.

Freedom from Defects

8. The wire shall be approximately circular in section, thoroughly annealed,* smoothly galvanised, and free from scale, inequalities, spills, splits, and other defects. Every coil may be examined for defects.

Each piece must be warranted to contain no weld, joint or splice whatever, either in the rod before it is drawn or in the finished wire.

Inspection

9. The Purchaser or his representative shall have the right to be present during all the stages of manufacture, and shall be afforded all reasonable facilities for satisfying himself that the wire is being manufactured in accordance with the terms of this Specification.

TESTS

General

10. The wire will be inspected and tested at the Contractor's Works. The Contractor shall supply without making any claim or charge for same, all the necessary machinery, apparatus, convenience, labour, and assistance required for the purpose. The testing plant shall be under the immediate control of the Purchaser or his representative during the tests. All the wire wasted in tests shall be supplied by the Contractor free of charge.

Test Samples

11. (*a*) Samples may be cut from the ends of every piece for the mechanical tests (see Clause 12).

(*b*) Not more than 5 per cent. of the test samples of any one size of wire will be cut from any part other than the ends for the mechanical tests. Pieces thus cut shall not be welded or otherwise jointed together, but each length shall be bound up into a separate coil. These pieces will be accepted and paid for if the wire satisfies all the requirements of this Specification.

(*c*) Any piece may be tested for electrical resistance.

The length to be tested shall, if desired by the Purchaser, be not less than $\frac{1}{20}$ English Statute mile. The piece will not ordinarily be

* The 60 lb. wire is required to give a relatively higher tensile test than the other sizes.

cut for this test, but similar test samples may be cut from not more than 2 per cent. of the pieces when it is desired to apply the test given in Clause 13. Test samples cut for this purpose will not be paid for.

Mechanical Tests

12. (*a*) *Twisting Test.*—The test sample shall withstand the following test without breaking.

It will be gripped in two vices, one of which will be made to revolve at a speed not exceeding one revolution per second for the minimum number of twists in the length as specified in the Table. The twists shall be indicated by means of an ink mark which will form a spiral on the wire during torsion, and the full number of twists shall be visible between the vices.

(*b*) *Tensile Test.*—The breaking load of the wire when tested as follows shall be not less than the values given in the Table.

A lever testing machine shall be used of which the accuracy can be easily checked, and the machine adjusted if necessary. The test sample as cut from the piece will be placed in the machine without being straightened, or prepared in any way, before testing. Nine-tenths of the minimum breaking load shall be applied quickly and the load shall then be increased steadily until the sample breaks. The time occupied in applying the remainder of the load shall be as nearly as possible five seconds, and the total time from the application of the load to the break shall be approximately twenty-five seconds.

ELECTRICAL TEST

Resistance

13. The electrical resistance of each test piece will be multiplied by

$$\frac{(D_1)^2 C}{(D)^2}$$

Where D_1 is the diameter of the test piece;
,, D is the standard diameter;
and C is the multiplier constant (temperature coefficient) for correcting to 60° F. (see Appendix).

In the event of dispute as to the diameter of any test piece, the Purchaser or his representative may have such test piece weighed, and if the weight per mile be either more or less than the standard weight, the resistance shall not be so high as that when multiplied into the weight per mile it would exceed the constant figure shown in the Table, and in all cases where the product is greater than this constant, the wire will be rejected.

Galvanising Tests

14. (*a*) The quality of the galvanising will be tested by immersing samples of the wire taken from the coils in a freshly made neutral solution of sulphate of copper saturated at 60° F., and allowing them to remain in the solution for one minute, after which they will be withdrawn and wiped clean. The galvanising shall admit of this process being performed four times with each sample without there being any sign

of a reddish deposit of metallic copper on the wire. In the case of the 100 lb. wire the fourth dip shall be of half a minute duration instead of one minute, and in the case of the 60 lb. wire the process shall only be performed twice.

Not more than three pieces of wire are to be imersed in the solution at one and the same time.

(*b*) The galvanised wire shall also stand the following test without the galvanised surface cracking :

The 800 lbs. size to bear winding round a bar 3 inches diameter.
" 600 " " " " 2½ " "
" 400 } " 300 } " " " " 1¾ " "
" 200 " " " " 1½ " "
" 100 " " " " 1 " "
" 60 " " " " ½ " "

TABLE

GALVANISED LINE WIRE

1	2	3	4	5	6	7	8	9	10	11	12
Weight per Statute Mile.			Diameter.			Minimum Breaking Load of Wire of Standard Weight.	Minimum Number of Twists.	Maximum Resistance per Mile of Standard Weight at 60° F.	Constant being Standard Weight per Mile × Resistance per Mile at 60° F.	Weight of each Piece (or Coil).	
Standard.	Minimum.	Maximum	Standard.	Minimum.	Maximum.					Minimum.	Maximum.
lbs.	lbs	lbs.	Inch.	Inch.	Inch.	lbs.		Ohms.		lbs.	lbs.
800	780	820	0·242	0·239	0·245	2400	12	6·66	5328	90	120
600	585	615	0·209	0·206	0·212	1800	15	8·88	5328	90	120
400	380	420	0·171	0·167	0·175	1200	22 In 6 ins.	13·32	5328	90	120
300	285	315	0·148	0·144	0·152	900	24	17·76	5328	70	120
*200	190	210	0·121	0·118	0·124	600	26	26·64	5328	50	120
*100	95	105	0·086	0·084	0·088	300	18 In 3 ins.	53·28	5328	50	120
*60	57	63	0·060	0·064	0·068	220	15	88·8	5328	15	30

* *Note.* - These wires may be delivered in bundles, provided that the weight of any bundle does not exceed 120 lbs.

Rejection

15. Any piece from which the test samples fail to pass any one of the requirements of this Specification may be rejected. Should 10 per cent. of the pieces in any parcel of wire fail to pass any of the requirements of this Specification, the whole of such parcel will be rejected. On no account shall any rejected parcel or any part thereof be again presented for examination and test.

Coiling and Labelling

16. The wire shall be coiled carefully. Unless otherwise specified, the eye of the coil shall be not less than 19, nor more than 21, inches when bound. Each coil shall be securely bound with four separate

APPENDIX

Multiplier Constant for Galvanised Line Wire

Temperature in Degrees F. at which Resistance is Measured.	Multiplier Constant for Converting to 60° F.	Temperature in Degrees F. at which Resistance is Measured.	Multiplier Constant for Converting to 60° F.
40	1·0571	70	0·9737
41	1·0541	71	0·9712
42	1·0511	72	0·9686
43	1·0481	73	0·9661
44	1·0452	74	0·9636
45	1·0422	75	0·9611
46	1·0393	76	0·9586
47	1·0364	77	0·9561
48	1·0335	78	0·9536
49	1·0306	79	0·9512
50	1·0276	80	0·9488
51	1·0249	81	0·9463
52	1·0221	82	0·9438
53	1·0193	83	0·9415
54	1·0165	84	0·9391
55	1·0137	85	0·9368
56	1·0109	86	0·9344
57	1·0082	87	0·9322
58	1·0054	88	0·9297
59	1·0027	89	0·9274
60	1·0000	90	0·9251
61	0·9973	91	0·9228
62	0·9966	92	0·9215
63	0·9920	93	0·9182
64	0·9890	94	0·9159
65	0·9867	95	0·9137
66	0·9841	96	0·9114
67	0·9814	97	0·9092
68	0·9788	98	0·9069
69	0·9761	99	0·9047
		100	0·9025

binders of galvanised iron wire of not less size than 100 lbs., nor greater than 300 lbs. per mile.

Each coil shall have securely attached to the inner part with 60 lbs. per mile galvanised wire :—

(*a*) A zinc label about 1¼ inches diameter, on which shall be distinctly stamped the maker's name, the year of supply, the size of the wire in lbs. per mile, and the weight of the coil to the nearest pound.

(*b*) A label of stout glazed linen, both ends doubled and eyeletted, with the address as specified on the order printed on it in bold characters.

Oiling

17. The coils, if so ordered, shall be thrice dipped in boiled linseed oil, after having been bound, labelled, and sealed. The oil shall be heated to a suitable temperature.

Weighing and Sealing

18 Every coil shall be weighed separately, and the weight stamped on the zinc label referred to above. Each coil will be sealed with a lead disc, which will bear the Purchaser's examination mark. All labels and discs shall be provided by the Contractor free of charge. The lead disc shall be perforated parallel to the face, so that the wire can be passed through it. The end of the wire will then be flattened and the disc slipped over the flattened portion and secured by one or two blows with a hammer and stamped.

No. 183—1923.

BRITISH STANDARD SPECIFICATION FOR GALVANISED STAY WIRE FOR TELEGRAPH AND TELEPHONE PURPOSES AND FOR SIGNAL POSTS

DEFINITIONS

Definition of Piece

1. The term "piece" shall denote a single length of wire without joint or splice of any description, either before being drawn or in the finished wire.

Definition of Strand

2. The term "strand" shall denote three or more wires twisted together.

Definition of Coil

3. The term "coil" shall denote one length of stranded wire in the form of a coil.

Definition of Bundle

4. The term "bundle" shall denote two or more coils properly bound together.

Definition of Parcel

5. The term "parcel" shall denote any quantity of finished wire presented for examination and test at any one time.

Definition of Test Sample

6. The term "test sample" shall denote a sample taken for test in accordance with the Specification.

MANUFACTURE

Material

7. The wire shall be of mild steel containing approximately 0·2 per cent. of combined carbon, and shall be galvanised with virgin spelter.

Dimensions

8. The wire shall be drawn in continuous pieces of the respective weights and diameters given in the Table.

Freedom from Defects

9. The wire shall be approximately circular in section, uniformly annealed, smoothly galvanised, soft, pliable, free from scale, inequalities, spills, splits, and other defects. Every coil may be examined for defects.

Lay and Stranding

10. The lay shall be right-handed and of the lengths given in the Table.

The wires shall be so stranded together that when an evenly distributed pull is applied at the ends of the completed strand, each wire will take an equal share of the pull.

Joints in Stranded Wires

11. Wires of No. 14 S.W.G. may be jointed together so as to make up coils of strand of the weights given in the Table. The joints in this wire shall be of the ordinary twist form, 2 inches long, and they shall be soldered with soft solder before the wire is stranded. Any length of strand which the Purchaser or his representative considers contains more than a reasonable number of joints may be rejected, and all joints shall be subject to his approval.

No joints or welds will be permitted in the No. 8 S.W.G. stranded wire. Lengths of wire of this gauge shall be selected so as to make up coils of stranded wire of the weights given in the Table.

Inspection

12. The Purchaser or his representative shall have the right to be present during all stages of manufacture, and shall be afforded all reasonable facilities for satisfying himself that the wire is being manufactured in accordance with the terms of this Specification.

TESTS

General

13. The wire will be inspected and tested at the Contractor's Works. The Contractor shall supply, without making any claim or charge for same, all the necessary machinery, apparatus, and labour required for the purpose. The testing plant shall be under the immediate control of the Purchaser or his representative during the tests. All the wire wasted in tests shall be supplied by the Contractor free of charge.

Test Samples

14. (*a*) Samples may be cut from the ends of every piece or strand for the mechanical tests (see Clause 15).

(*b*) Not more than 5 per cent. of the test samples of any one size of wire will be cut from any part other than the ends for the mechanical tests. Pieces thus cut shall not be welded or otherwise jointed together, but each length shall be bound up into a separate coil. These pieces will be accepted and paid for if the wire satisfies all the requirements of this Specification.

Mechanical Tests

15. (*a*) *Twisting Test.*—This test shall be applied only to the wires before they are stranded.

The test sample shall withstand the following test without breaking. It will be gripped in two vices, one of which will be made to revolve at a speed not exceeding one revolution per second for the minimum number of twists in the length as specified in the Table. The twists shall be indicated by means of an ink mark which will form a spiral on the wire during torsion, and the full number of twists shall be visible between the vices.

NOTE.—When the purchaser cannot test the single wire before stranding the test shall be carried out on a single wire taken from a strand, in which case the number of twists shall be reduced by two.

(*b*) *Elongation Tests.*—The elongation tests will be made by gripping the samples, 10 inches long, in an elongation machine, and steadily elongating the sample until it breaks. The duration of the tests shall be approximately 30 seconds. The elongation shall be measured after fracture, and shall comply with the figures given in the Table.

(*c*) *Tensile Test of Wire.*—The minimum breaking load of the wire when tested before stranding shall be in accordance with the values given in the Table.

A lever testing machine shall be used of which the accuracy can be easily checked, and the machine adjusted, if necessary. The test sample of wire as cut from the piece shall be placed in the machine without being straightened or prepared in any way, before testing. Nine-tenths of the minimum breaking load shall be applied quickly, and the load shall then be increased steadily until the sample breaks. The time occupied in applying the remainder of the load shall be as nearly as possible 20 seconds, and the total time from the application of the load to the break shall be approximately 30 seconds.

(*d*) *Tensile Test of Complete Strand.*—The minimum breaking load of the complete strand shall be in accordance with the Table.

The ends of the strand shall be suitably prepared either by filling in the interstices between the strand wires with smaller gauge wire or other approved means, and the load shall be gradually applied in approximately the same manner as in the case of the single wire.

Galvanising Tests

16. (*a*) The quality of the galvanising will be tested by immersing samples of the wire before stranding in a freshly-made neutral solution of sulphate of copper saturated at 60° F. and allowing them to remain in the solution for one minute, when they will be withdrawn and wiped clean. The galvanising shall admit of this process being performed four times with each sample without there being any sign of a reddish deposit of metallic copper on the wire. In the case of the No. 14 S.W.G. wire, the fourth dip shall be of half a minute duration instead of one minute.

Not more than three pieces of wire are to be immersed in the solution at one and the same time.

(*b*) The galvanised wire before stranding shall also stand the following tests without the galvanised surface cracking :—

No. 8 S.W.G. to bear winding round a bar 2 inches diameter.
No. 14 S.W.G. „ „ „ ¾ inch diameter.

TABLE

GALVANISED STAY WIRE

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
				Single Wire.								Stranded Wire.						
				Diameter.						Minimum Number of Twists.					Weight of each Coil.		Diameter of Eye of Coil.	
Item No.	Designation.	Number of Wires.	S.W.G.	Standard.	Minimum.	Maximum.	Elongation per Cent.	Elongation per Cent. (on Single Wire after Stranding).	Minimum Breaking Load.	In 6 Inches.	In 3 Inches.	Weight per Mile.	Length of Lay.	Minimum Breaking Weight.	Minimum.	Maximum.	Minimum.	Maximum.
				inch.	inch.	inch.			lbs.			lbs.	inch.	lbs.	lbs.	lbs.	inch.	inch.
1	BB. 1	7	14	0·080	0·077	0·083	12	10	350	—	16	625	3¾	2450	120	210	12	13
2	BB. 3	3	8	0·160	0·156	0·164	15	12	1400	16	—	1050	8	4200	120	210	26	30
3	BB. 4	4	8	0·160	0·156	0·164	15	12	1400	16	—	1400	9	5600	120	210	26	30
4	BB. 5	5	8	0·160	0·156	0·164	15	12	1400	16	—	1750	10	7000	120	210	26	30
5	BB. 7	7	8	0·160	0·156	0·164	15	12	1400	16	—	2450	11	9800	120	210	26	30

Rejection

17. Any piece from which the test samples fail to pass any one of the requirements of this Specification may be rejected. Should ten per cent. of the pieces in any parcel of wire fail to pass any of the requirements of this Specification, the whole of such parcel will be rejected. On no account shall any rejected parcel, or part thereof, be again presented for examination and test.

Packing

Marking and Packing Accepted Material

18. The strand shall be smoothly and uniformly coiled so that the eye of the coil shall be in accordance with the figures given in the Table. Each coil shall be securely bound with four separate binders of galvanised wire of a size not less than 100 lbs. nor greater than 300 lbs. per mile, and in no case shall two or more pieces or strands be linked or otherwise jointed together.

The coil shall be delivered properly bound within the limits of weight shown in the Table. Each bundle shall be weighed separately and labelled with a metal or other approved label marked with the maker's name, designation of wire, weight of bundle to nearest pound, and year of supply. The label shall be firmly affixed to the inner part of the coil or bundle.

Each bundle shall be wrapped in canvas and be packed and delivered as ordered.

Oiling

19. Coils, if so ordered, shall be dipped in boiled linseed oil after having been bound, labelled, and sealed. The oil shall be heated to a suitable temperature.

No. 184—1923.

BRITISH STANDARD SPECIFICATION FOR GALVANISED BINDING AND JOINTING WIRE FOR TELEGRAPH AND TELEPHONE PURPOSES

Definitions

Definition of Piece

1. The term "piece" shall denote a single length of wire without joint or splice of any description, either before being drawn or in the finished wire.

Definition of Coil

2. The term "coil" shall denote one piece of wire in the form of a coil.

Definition of Bundle

3. The term "bundle" shall denote two or more coils properly bound together.

Definition of Parcel

4. The term "parcel" shall denote any quantity of finished wire presented for examination and test at any one time.

Definition of Test Sample

5. The term "test sample" shall denote a sample taken for test in accordance with the Specification.

MANUFACTURE

Material

6. The wire shall be a low carbon steel containing approximately 0·1 per cent. of combined carbon, and shall be galvanised with virgin spelter.

Dimensions

7. The wire shall be drawn in continuous pieces of the weight and diameter given in the Table.

Freedom from Defects

8. The wire shall be approximately circular in section uniformly annealed, smoothly galvanised, soft, pliable, free from scale, inequalities, spills, splits, and other defects. Every coil may be examined for defects.

Inspection

9. The Purchaser or his representative shall have the right to be present during all stages of manufacture, and shall be afforded all reasonable facilities for satisfying himself that the wire is being manufactured in accordance with the terms of this Specification.

TESTS

General

10. The wire will be inspected and tested at the Contractor's Works. The Contractor shall supply, without making any claim or charge for same, all the necessary apparatus and labour required for the purpose. The testing apparatus shall be under the immediate control of the Purchaser or his representative during the tests. All the wire wasted in tests shall be supplied by the Contractor free of charge.

Test Samples

11. Samples may be cut from the ends of every piece for the Mechanical Tests (see Clause 12).

Mechanical Test

12. *Twisting Test.*—The test sample shall withstand the following test without breaking:—

It will be gripped in two vices, one of which will be made to revolve at a speed not exceeding one revolution per second for the minimum number of twists in the length as specified in the Table. The twists shall be indicated by means of an ink mark which will form a spiral on the wire during torsion, and the full number of twists shall be visible between the vices.

Galvanising Tests

13. The quality of the galvanising will be tested by immersing samples of the wire taken from the coils in a freshly-made neutral

solution if sulphate of copper saturated at 60° F., and allowing them to remain in the solution for one minute, after which they will be withdrawn and wiped clean. The galvanising shall admit of this process being performed four times with each sample of the 200 lb. wire without there being any sign of a reddish deposit of metallic copper on the wire. In the case of the 60 lb. wire, the process shall only be performed twice.

Samples taken from any coil or coils shall also bear winding round a bar 1½ inch in diameter in the case of the 200 lb. wire, and round a bar of ¼ inch in diameter in the case of the 60 lb. wire, without any sign of the zinc cracking or peeling off.

Rejection

14. Any piece from which the test samples fail to pass any one of the requirements of this Specification may be rejected. Should 10 per cent. of the pieces in any parcel of wire fail to pass any of the requirements of this Specification, the whole of such parcel will be rejected. On no account shall any rejected parcel or any part thereof be again presented for examination and test.

Packing

Marking and Packing Accepted Material

15. The wire shall be smoothly and uniformly coiled, each coil being separately bound, and in no case shall two or more pieces be linked or otherwise jointed together. The coils shall be made up in bundles properly bound and within the limits of weight shown in the Table.

Each bundle shall be weighed separately and labelled with a metal or other approved label marked with the maker's name, the designation of wire, weight of bundle to the nearest pound, and year of supply. The label shall be firmly affixed to the inner part of the coil or bundle.

Each bundle shall be wrapped in canvas and be packed and delivered as ordered.

TABLE

Galvanised Binding and Jointing Wire

1	2	3	4	5	6	7	8	9	10	11	12
Designation.	Diameter.			Weight per Mile.			Number of Twists in 3 inches.	Weight of Each Coil.		Weight of Each Bundle.	
	Standard.	Minimum.	Maximum.	Standard.	Minimum.	Maximum.		Minimum.	Maximum.	Minimum.	Maximum.
	inch.	inch.	inch.	lbs.	lbs.	lbs.		lbs.	lbs.	lbs.	lbs.
AA 21 .	0·066	0·064	0·068	60	57	63	25	5	14	10	42
AA 22 .	0·121	0·118	0·124	200	190	210	20	56	112	112	336

CHAPTER IV

WOOD

For telephone and telegraph purposes the kinds of wood that are chiefly used are :—

Soft Woods.—Yellow or red deal, white deal, pitch pine, and Oregon pine.
Hard Woods.—Ash, oak, elm, teak, Karri, and some other Australian woods obtained from eucalyptus trees.
Cabinetmaking Woods.—Walnut, mahogany, and teak.

To enable the different kinds of wood to be identified from their appearance after being worked by the carpenter or joiner, some knowledge of the general structure of timber is helpful. Beginning with soft woods, which are obtained from cone-bearing trees or coniferæ, the transverse section shows a series of concentric rings, each ring made up of two concentric parts, the inner part being lighter in colour than the outer. Each ring shows the amount of wood added to the tree in one year, and consequently the age of a felled tree can be ascertained by counting these rings, which are usually referred to as annual rings. Wood has a cellular structure, and the darker portion of the annual ring owes its colour to the closer packing or squeezing together of the wood cells. This darker part of the ring is produced during the long sunny days of summer, when the bark is strong and compresses the cells, whereas the lighter part of the ring is produced in the spring, when the bark is relatively weak and cracked and able to exert but little pressure on the cells. Each annual ring, therefore, consists of two parts—the light coloured or spring wood, and the dark coloured or summer wood. The greater the proportion of summer to spring wood the denser and stronger the wood is, and therefore the general appearance and colour of soft woods is some indication of their quality. The appearance of pitch pine and Oregon pine is very marked in this respect. The best qualities of red or yellow deal also show a considerable proportion of summer wood, but in white deal the summer wood is less prominent. Fig. 30 shows the cellular structure of a piece of spruce—from which large quantities of white deal are obtained—and it will be seen from the figure how well marked the compression of the summer cells is, although this wood generally shows but a small proportion of summer wood. It will also be seen from the figure that in addition to the vertical cells, there are several series of cells running at right angles to them. These are called medullary rays.

In trees of the cone-bearing class these rays are not visible to the naked eye, but in some of the hard woods, notably oak, they are much larger, and are not only visible to the naked eye but account for the characteristic figure or silver grain.

Hard Woods.—The principal difference in the structure of soft and hard woods is the presence in the latter of large tracheæ or vessels which are not found in woods of the cone-bearing class.

In oak, ash, and elm the annual ring is readily seen, but it does not show any sharp difference in colour as in the soft woods, there being a ring system of vessels on the inner edge of the annual rings.

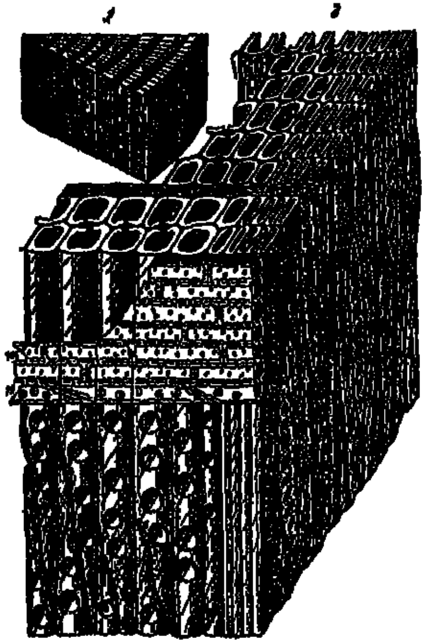


FIG. 30.—1. Piece of wood from a spruce fir, natural size. 2. A portion from the nearest upper outside angle of 1, showing summer wood (to the right) and spring wood. Supposed to be magnified about 100 times. From Hartig's "Timbers, and How to Know Them."

These vessels are continuous throughout the length of the tree, and it is obvious that since they are relatively large empty tubes they do not contribute so much to the strength of the wood as the more solid parts. Fig. 32 is a photograph of a piece of excellent ash, showing how the vessels or vascular tissue wear away in advance of the more solid parts of the annual rings. This piece of ash had been used in a wood-working machine, and the end grain had been bombarded with small chips and sawdust with the result shown.

A somewhat similar effect can be seen on a well-worn scrubbing-board made of white deal, where the summer wood stands up in ridges whilst the spring wood is worn into furrows. It is well,

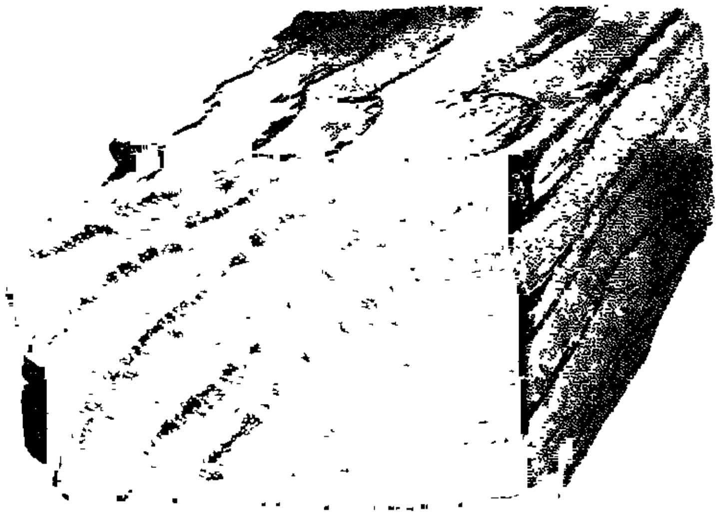


FIG. 32.—Piece of Ash showing effect of Bombarding End Grain with Sawdust. Vascular Tissue wears away quicker than other part of Annual Ring.

therefore, to note that whereas in cone-bearing trees the more annual rings there are to a radial inch, or, what is the same thing, the slower the growth the stronger the wood will prove, but with hard woods of the oak, elm, and ash class the contrary is true, and the larger the proportion of solid wood to vascular tissue the stronger and better it will prove, other things being equal. The table of tests on pp. 56-57 shows what a tremendous difference in strength and flexibility there is between samples cut from badly-grown and well-grown ash trees.

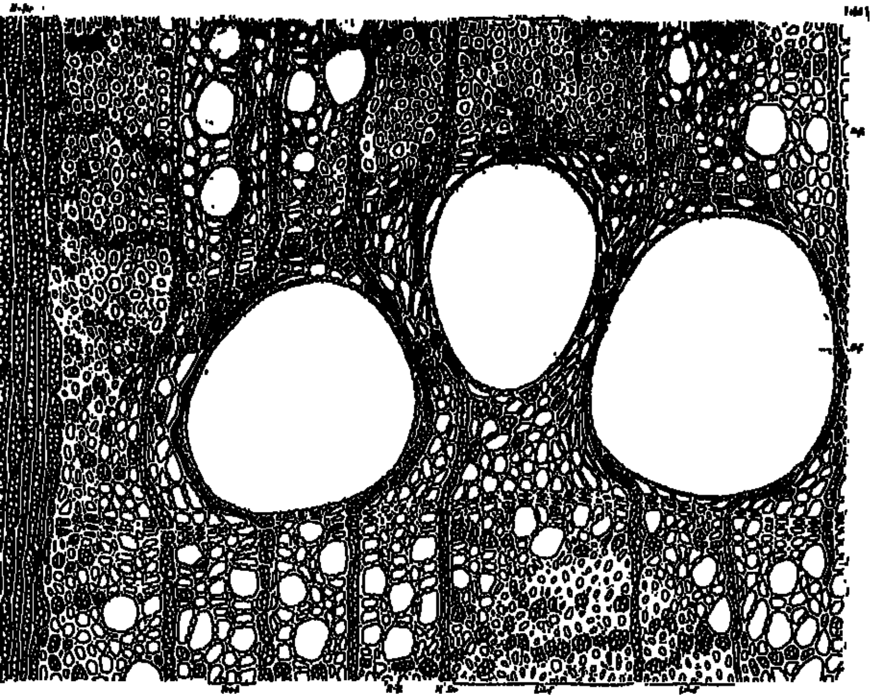


FIG. 31.—Transverse section of oak highly magnified, showing the large tracheæ or vessels (*Gef.*). From Marshall Ward's "The Oak."

These samples were prepared three months before testing, and were kept during that time in a room at a temperature of approximately 60° F., so that as regards dryness they were practically alike. Carefully air-dried wood is much stronger than when it is wet.

From the table it will be seen that the modulus of rupture of sample No. 9 is the lowest of all the samples tested, viz., 282 lbs., whilst the number of annual rings per radial inch is greater than in any other sample, viz., eighteen. This sample is also one of the lightest in weight, and it is clear that slow growth in this class of wood is not conducive to good quality. The sample with the highest modulus of rupture is No. 2, with 1092 lbs., and it is noteworthy

TABLE

Number of Sample.	Weight of 42 Inch Length.	Weight per Cubic Inch.	Number of Rings per Radial Inch.	Temporary Deflection in Inches at								
				28	56	84	112	140	168	196	224	252
	ozs.	ozs.										
1	17	·405	16 13	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{15}{16}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$1\frac{11}{16}$
2	17	·405	10 7	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{7}{8}$	1	$1\frac{1}{8}$
3	$16\frac{1}{4}$	·387	6 5	$\frac{1}{8}$	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$1\frac{7}{8}$	$2\frac{1}{4}$	$2\frac{7}{8}$
3A	$17\frac{1}{2}$	·417	10 10	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{3}{8}$
3B	15	·357	4 8	$\frac{1}{8}$	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{5}{8}$	$2\frac{1}{8}$	$2\frac{1}{2}$	—
4	10	·238	13 12	$\frac{1}{8}$	1	$1\frac{1}{2}$	$2\frac{1}{4}$	—	—	—	—	—
5	$9\frac{1}{2}$	·226	11 7	$\frac{3}{8}$	$1\frac{1}{4}$	$2\frac{1}{8}$	{98 lbs. $2\frac{1}{2}$}	—	—	—	—	—
6	$16\frac{3}{4}$	·399	8 10	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{1}{8}$	$1\frac{3}{8}$
7	11	·262	10 13	$\frac{3}{8}$	1	$1\frac{1}{2}$	$2\frac{1}{4}$	4	—	—	—	—
8	12	·286	14 7	$\frac{3}{8}$	$\frac{5}{8}$	1	$1\frac{1}{4}$	$1\frac{3}{4}$	$2\frac{1}{4}$	—	—	—
9	10	·238	18 18	$\frac{3}{8}$	$\frac{5}{8}$	$1\frac{1}{4}$	—	—	—	—	—	—
10	19	·452	7 5	$\frac{1}{8}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2
11	$15\frac{3}{4}$	·375	10 6	$\frac{1}{8}$	$\frac{3}{8}$	$\frac{5}{8}$	$1\frac{1}{4}$	$1\frac{5}{8}$	$2\frac{3}{8}$	—	—	
12	14	·333	16 17	$\frac{1}{8}$	$\frac{3}{8}$	$\frac{5}{8}$	1	$1\frac{3}{8}$	$1\frac{3}{4}$	$2\frac{1}{4}$	3	—
13	$16\frac{1}{2}$	·393	9 8	$\frac{1}{8}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	—	—	—	—
14	15	·357	10 16	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{5}{8}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{7}{8}$	—	—

All samples were of 1 inch square section. Load was applied in the middle.
same sample if loaded in the middle, but

Load of— 280	Load of— 308	Load of— 336	Breaking Load.	Modulus of Rupture.	Appearance of Sample before Test.	Kind of Fracture.
			lbs.			
$2\frac{1}{2}$	3	—	350	1050	Slow grown, but pores in spring wood small.	Long, but rather dull in appearance.
$1\frac{1}{2}$	$1\frac{5}{8}$	$2\frac{1}{4}$	364	1092	Cross-grained and irregular in growth, but otherwise good, bright-looking sample.	Broke along cross-grain; good fracture otherwise.
4	—	—	—	—	Slightly cross-grained, but otherwise good sample.	Not broken.
$1\frac{1}{2}$	$1\frac{7}{8}$	$2\frac{1}{4}$	350	1050	Straight-grained, good-looking sample.	Long fracture; crack not extending beyond neutral axis.
—	—	—	252	756	Badly cross-grained, but otherwise good sample.	Broke with rather short fracture at cross-grained part.
—	—	—	136	408	Poor dull-looking sample but straight grained.	Broke at three places at the same instant with short fractures.
—	—	—	98	294	Large pores and rather brown sample.	Broke with very short fracture like a carrot.
—	—	—	266	798	Badly cross-grained and rather brown, but otherwise fair sample.	Broke short across the grain.
—	—	—	—	—	Growth irregular, some rings large, some small; fairly straight-grained.	Did not break.
—	—	—	168	504	Growth irregular; brown powdery-looking sample.	Broke in two places at same instant. Poor fracture.
—	—	—	94	282	Very slow grown; pores large; colour brown; dull-looking sample.	Broke in two places at same instant. Short fractures.
$2\frac{5}{8}$	3	—	315	945	Badly cross-grained and contains dead knot. Otherwise good sample.	Broke in middle at cross-grain and also at support at live knot.
—	—	—	168	504	Cross-grained, dull-looking sample.	Broke in middle at cross-grain.
—	—	—	—	—	Straight grained, but slow grown; brown colour.	Did not break; maximum deflection 4 ins. at load of 238 lbs.
—	—	—	168	504	Badly cross-grained and rather brown colour.	Broke at cross-grained part.
—	—	—	224	672	Cross-grained and rather brown in colour.	Broke at cross-grained part.

Supports 36 inches apart. Modulus of rupture = Breaking weight in lbs. of distance between supports 12 inches.

that the weight per cubic inch is nearly double that of sample No. 9, and the number of annual rings per radial inch about one-half. Another characteristic of inferior ash is a brownish colour, especially when it is associated with large vessels and a dull scrubby appearance. It is true that the heartwood of very old ash trees turns brown, almost black, although it appears to be quite sound and well grown. For ordinary purposes, however, it may be said that the whiter the ash and the smaller the proportion of vessels in the annual rings, the stronger and tougher the wood will be, and in general the weight per cubic inch will vary with these properties. Oak and elm wood are similar in structure to ash as regards vessels or vascular tissue, and the same general remarks apply. The dominating characteristic in the appearance of oak is the presence of the conspicuous medullary rays, which start from the medulla or centre pith, and in some cases extend almost to the outside edge. Whenever the medullary rays are exceptionally large and of considerable width, the wood is likely to be weak and brittle. The medullary rays in ash and elm, although present, cannot be seen with the naked eye, whereas they can always be seen in oak. In other respects, ash and oak resemble each other in appearance rather closely, and it is not always easy to tell off-hand whether a small round sample is ash or oak, if the transverse section is not available for inspection. It is a remarkable property of the elm tree that it will throw out shoots and branches from the bark all the way up the tree, and on account of this unequal growth of the section of the tree, the annual rings are seldom circular, but follow an irregular and wavy outline. The elm tree is often badly treated by the farmer, who, to ensure that the sunlight shall reach his land, lops off all the branches so that the tree resembles a giant cabbage stalk. The proportion of vascular tissue is necessarily larger when the tree is starved through this excessive lopping, and where strength is indispensable a good open growth is essential. For telephone purposes elm is chiefly used for the hubs of wheels of hand-carts, and for the trays of excavators' barrows. The other hard woods are dealt with later under the heading of "Arms."

Cabinetmaking Woods.—Walnut, mahogany, and occasionally teak, are used for switchboards, telegraph test boards, etc., and the last-named for pole test boxes. Honduras mahogany is largely used for the woodwork of instruments and wall boards, and although not of such a deep rich colour as Spanish or Cuban mahogany, it is generally straight-grained and takes a good polish. Walnut is the principal wood used for small switchboards, and American walnut which is of fine grain and striking figure, produces when well matched a handsome effect. This question of matching is one of some importance, as the appearance of a switchboard may be spoilt by the jointing of a rather light coloured sappy piece to a rich coloured heartwood. When the board is examined before polishing, or in the white as it is sometimes termed, this point should receive attention, so as to prevent an unworkmanlike job being perpetuated. Teak is a wood that is handsomer than it is sometimes

given credit for, and large test boards made in teak have proved very durable and equal in appearance to mahogany. It is the only wood used in the construction of pole test boxes, and it has proved the most durable for this purpose, standing exposure to all weather better than any wood. It is necessary to select teak carefully, because it occasionally has a deposit of hard crystals in the grain that renders it hard to cut, and tends to blunt the tools. It is somewhat unpopular in some quarters, due to its oily character, but no trouble on this account has been experienced in the Post Office factories.

Canary whitewood is of the lime family, and is easily recognised by its compact grain and colour. It takes stains readily, and is used for cheap construction where the more expensive hardwoods are not called for. It is a very tough and strong wood, and if well seasoned gives good results for cheap cabinet work like small cupboards, etc.

Defects in Timber.—The most frequent defect met with in soft woods is the *shake* or split which results from the natural drying of the wood. If the wood is worked before it is properly dry, this defect will develop in the finished article. The manner in which the wood contracts as it dries or seasons is worthy of notice. The outermost part containing the sapwood is always the wettest, and consequently the contraction or shrinkage after converting the log into planks is greatest on the outside annual rings. As the tension increases, due to the shrinkage, the wood splits at the weakest parts, which are found to be in the plane of the medullary rays. The split or shake is widest at the outside, and tapers towards the heart when it is due to this cause. The shakes in a standing telegraph pole illustrate the way the wood contracts circumferentially, all the shakes being practically vertical. It may safely be said that there is no shrinkage in the direction of the length of the wood due to drying, but only *along* the circumference of the annual rings, the outer rings shrinking more than the inner ones, with consequent development of shakes on the outside part. In planks sawn tangentially to the annual rings one side of the plank will be more likely to develop a shake than the other, and the wider the plank is the more likelihood there will be of a shake developing. Pitch pine especially shrinks considerably as it dries, and it is no uncommon experience with wide pitch pine boards for the width to shrink $\frac{3}{8}$ of an inch, whilst there is practically no shrinkage in the length of the board. If the reader happens to have an old pitch pine cupboard or press in his office, it may prove of interest to examine the panels for shrinkage, as it can generally be readily seen along the edges of the width, but not on the top and bottom edges, although when the cupboard was put together by the joiner the wood may have appeared thoroughly seasoned and dry. Advantage is sometimes taken of the fact that wood does not shrink in the direction of its length (that is, along the fibre) by glueing together two boards with the grain in one running at right angles to the grain in the other, so that they mutually resist contraction in each other, and prevent shakes developing. It is not, however, true to say in all cases that wood is unseasoned

from Sweden, Norway, and Northern Russia, and to a limited extent from home-grown sources. The chief requirement in a pole is that it shall be strong enough for the purpose, but it is necessary to have special regard for its appearance when erected, and straightness is therefore indispensable. When subjected to stress it behaves principally as a cantilever, with the maximum bending moment at the ground line. It is desirable, therefore, that the pole shall show a fair taper and be free from rings or whorls of knots and large knots at the part where the ground line will come when the pole is erected say, 5 feet from the butt end. In the following table, which is taken, from a paper read by the author at the International Telegraph Conference, held in Paris in 1910, will be found the results of the mechanical tests of some representative poles, some of the poles being new and others after having been in service many years. The length of service is given in the table. The method of testing will be gathered from the photographs, but perhaps a brief description of the apparatus will facilitate the comprehension of the details. The large end of the pole was inserted to a length of about 5 feet between the two halves of a split cylinder made of iron, and supported on wood rings up to the fulcrum, which was arranged so that the greatest bending moment might come at that part of the pole which was at the ground line when the pole was in service. The split cylinder containing the pole was supported in a horizontal position on a braced wood structure, and the load was applied at the end of the pole by means of a suspended wood platform upon which the weights were placed, the deflection being measured at each addition of 1 cwt. As the mass of the length of pole protruding from the cylinder assisted the stress, it was necessary to determine the weight of this portion, and to ascertain its centre of gravity. It was deemed too cumbrous to determine these figures by actual experiment, and the following approximate calculation was accordingly made. Three of the poles were weighed, their volume calculated from their dimensions, and from these data an average specific gravity for the three poles was obtained, the value being 0·63. The poles were all practically circular in section, and the centre of gravity was therefore readily calculated as follows :—

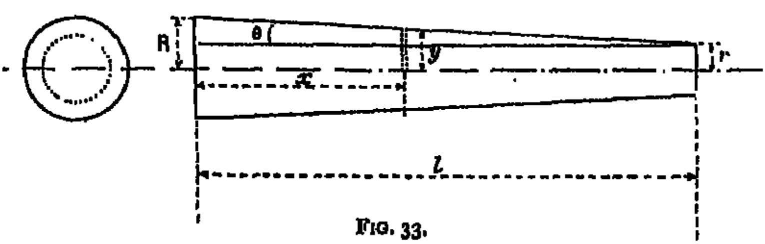


FIG. 33.

$$\Sigma mx = \bar{x}\Sigma m$$
$$\rho\Sigma vx = \bar{x}\rho\Sigma v.$$

Area at any point, $x = \pi y^2$.
Volume of length, $\delta x = \pi y^2 \delta x$.

$$Y = \left[R - x\left(\frac{R-r}{l}\right)\right]$$

$$\int_0^l \pi y^2 x dx = \bar{x}\int_0^l \pi y^2 dx$$

$$\bar{x} = \frac{l}{4}\left[\frac{(R+r)^2 + 2r^2}{R^2 + Rr + r^2}\right].$$

The moment thus obtained has been allowed for in the final breaking load shown in the table. In order that the results may be readily compared, the modulus of rupture has been calculated from the results, and is shown in the table. The modulus of rupture is the theoretical breaking load of a beam of the same material as the test sample, 1 inch square section, span 1 foot, loaded in the middle.

Test No.	No. of Years in use as Telegraph Pole.	Length of Pole.	Leverage.	Radius. At Top.	Radius. At Point of Maximum Bending Moment.	Total Breaking Loads.	Modulus of Rupture.	Remarks.
		ft. ins.	feet.	inches.	inches.	lbs.		
445	26	25·8	19	2·78	3·62	1085	368	
446	26	25·8	19	3·00	3·81	1151	336	Broke at ring of small knots close to point of support.
447	26	25·8	20	2·75	3·81	1315	403	
448	26	25·8	20	3·06	3·87	1271	372	
449	20	22·6	15	4·00	4·75	2749	327	Pole had decayed at the top.
468	36	30·0	24	3·66	4·45	1615	373	
469	38	34·0	27	3·42	4·89	2306	452	
470	38	34·0	27	3·66	4·93	1762	337	Broke at large dead knot 7 feet from point of support.
471	37	32·0	25	3·56	4·69	1847	380	
583	New Creosoted	27·11	22	2·62	3·52	865	371	
584	Do.	28·1	22	2·80	3·85	1231	402	
585	New, not Creosoted	27·11	22	2·66	3·40	962	457	
586	Do.	28·0	22	2·70	3·58	964	392	Spiral seasoning split.

To calculate the modulus of rupture we have, for the pole,

$$M = WL = CZ$$

where
$$Z = \frac{I}{y} = \frac{\pi R^4}{4R} = \frac{\pi R^3}{4}.$$

$$\therefore W = C\frac{\pi R^3}{4L},$$

and for a square beam loaded in the middle

$$M_1 = \frac{W_1 L_1}{4} = CZ = C\frac{BD^2}{6}$$

if $$B = D = 1 \text{ inch}$$

and $$L_1 = 1 \text{ foot}$$

$$W_1 = \tfrac{2}{3}C.$$

Dividing W_1 by W we get

$$W_1 = \frac{8}{3}\frac{WL}{\pi R^3}.$$

Fig. 34 is a photograph of test No. C446. This pole had a ring of small knots at the point of maximum bending moment, and Fig. 35 is a photograph of the pole taken immediately after the test. It will be noticed that the pole has broken short "like a carrot." Fig. 36 is a photograph of test No. C468. This pole had been in service for thirty years prior to being tested, and yet it was so tough that it deflected so much before fracture that it was necessary to dispense with the platform and to tie the weights direct on to the pole to get a fracture. In Fig. 36 the platform is quite clear of the ground, and the pole at this stage had not broken. Fig. 37 is a photograph at the final breaking load. The fracture is a good long one, and can be just faintly seen in the photograph. The modulus of rupture of C468 is 10 per cent. higher than that of C446, although C468 had seen ten years more service than C446. It is clear, therefore, that although the ring of small knots did not prevent the latter from being used satisfactorily for twenty-six years, nevertheless it might have failed in service in circumstances where a pole like C468—free from a ring of knots—would have proved successful. Test No. C449 is of a pole that had begun to decay in the heartwood at the top of the pole, although so far as could be seen it was quite sound at the ground line. The modulus of rupture of C449 is the lowest shown in the table, and the weakness is probably due to the incipient decay of the pole. Test C470 was of a pole which had a large dead knot near to the ground line, and the break occurred at this knot. The modulus of rupture is nearly as low as that of C449. Test C586 was of a pole that showed a long spiral split (making an angle of 5° with the axis of the pole), indicating that it was not straight grown. The modulus of rupture of this pole is much lower than that of C585, which was a somewhat similar pole as regards size and pitch of annual rings, but of straight growth.

When poles are being dressed, prior to being creosoted, care must be taken to cut away as little as practicable of the natural sapwood, and to pare this sparingly, because it is only into this section of the pole that the preservative—creosote oil—can pene-

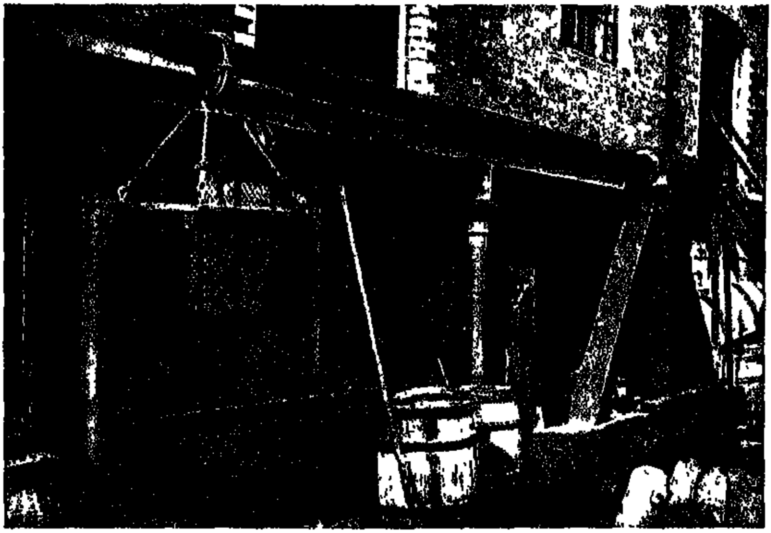


FIG. 34.—Pole Gripped ready for Testing. Test No. C446.

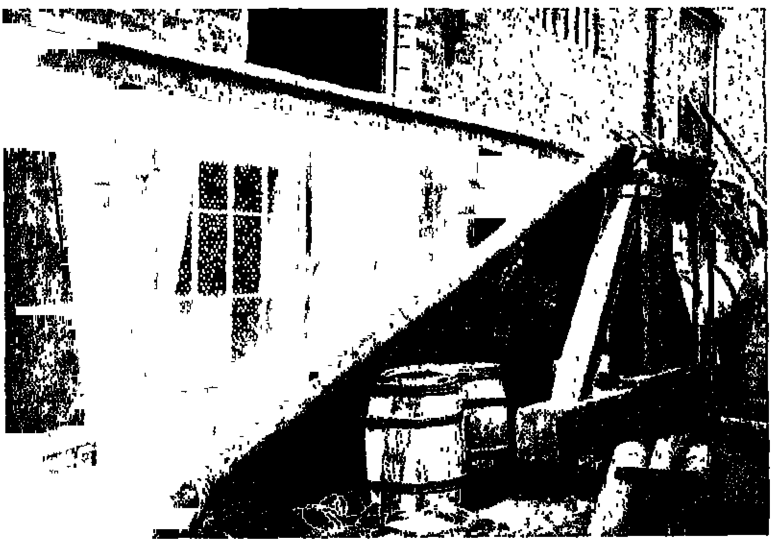


FIG. 35.—Pole after Fracture. Test No. C446.

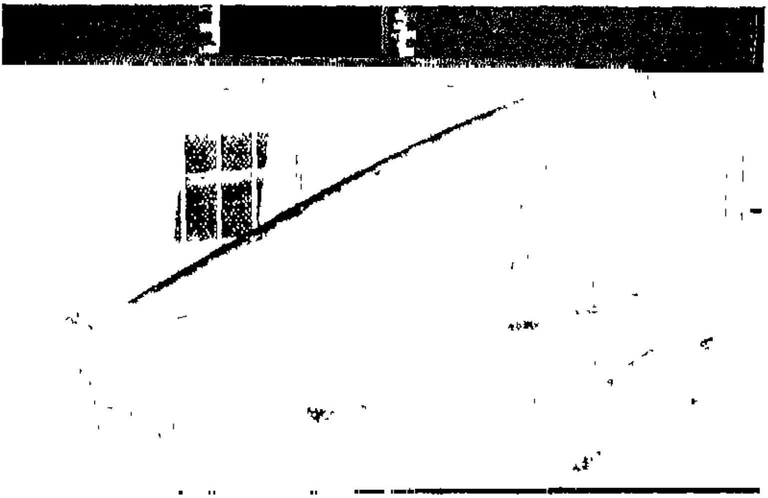


FIG. 36.—Pole Deflected but not Broken. Test No. C468.

FIG. 37.—Pole after Fracture. Test No. C468.

trate. The heartwood is practically impervious to the creosote under practical conditions. The timber should be winter felled when the sap is down, so as to facilitate seasoning, and the subsequent preservative impregnation. The strength of timber is affected by the amount of moisture the timber contains, and from a long series of tests it appears that wood containing about 15 per cent. of moisture is at its maximum strength. For this reason probably winter-felled timber, when tested, soon after felling is stronger than summer-felled timber. The closer the annual rings are packed, that is to say, the more there are to a radial inch, the greater strength the wood will probably show when tested, and for this reason specifications generally call for closely pitched annual rings. The pole should contain the natural butt of the tree, that is, the tree should be sawn off as close to the ground as possible, as this section of the tree is of the hardiest growth. The end should be sawn to give a flat section, and the sapwood should not be excessively trimmed or cut away, for the reasons stated above. When left in water for long periods of time, poles become water-logged and will eventually sink. It is generally stipulated, therefore, that when poles have to be floated or immersed in water to facilitate handling, they shall not be allowed to remain so immersed longer than seven days.

Spruce fir telegraph poles are largely used in Austria, and they are creosoted by a patent process (the Haltenberger process). This process provides for pricking the pole at intervals for about 18 inches above and below the assumed ground line, whereby the creosote is satisfactorily injected. The methods of creosoting employed in England do not give satisfactory results when applied to spruce, because this wood is practically free from sapwood, and consequently this timber has not been used for telegraph poles here. Home-grown larch has given good results when properly creosoted, but occasionally failures have occurred, and while red fir can be economically obtained it is unlikely that larch will effectively compete with it.

Pitch pine and Oregon pine are used only for terminal poles. They are generally converted to a square section and painted. They should be well-hearted, the heart being in the middle section of the pole and not eccentric, as may well be the case if in converting to a square section this point is overlooked. If the heart is eccentric the pole will shrink more on one side than on the other, and large seasoning cracks will probably develop. These poles should be free from sapwood.

Telegraph Arms.—In the early days of the industry telegraph arms were made from British and Russian oak, but supplies of suitable oak have not been plentiful in recent years, and it has consequently been necessary to use other hard woods. Fortunately the Australian hard woods obtained from the large family of eucalyptus trees are well suited to the purpose, and it may be said that karri and spotted gum have been more largely used in the United Kingdom for telegraph arms in the last twenty years than any other kind of timber. All the wood obtained from eucalytpus

trees is very heavy, and some of it is so heavy that it sinks when placed in water. The heavier kinds of eucalyptus woods are not favoured by some authorities, as there is a limit to the load that can be safely put on the top part of a telegraph pole. In addition to karri and spotted gum, smaller quantities of blue gum, blackbutt, ironbark, jarrah, and other woods of the same family have been used. These woods are remarkably fibrous in character, and when tested to destruction show long fractures of coarse fibre. As imported, these woods are generally free from knots and very straight grained, but some varieties occasionally contain large gum veins. These gum veins are generally a cause of rejection, because when subjected to the sun's heat after erection the gum would be likely to flow out and render the wood too weak for telegraph purposes. It is usual to stipulate, therefore, that for telegraph arms the wood shall be free from gum veins. Whether the arm is made of karri, oak, or any other kind of wood, it is imperative that the grain of the wood shall be reasonably parallel to the edge of the arm, otherwise the arm will be weak. All timber is weaker across the grain than along the grain. When oak is used the arm should be made so that the medullary rays will be approximately at right angles to the holes for the insulator spindles. The medullary rays are planes of weakness, especially in oak, and they are of least detriment when the spindle holes are bored, as stated above. The arms should be quite straight, not only on account of appearance when erected, but also to ensure that the correct distance between the wires is maintained, especially on routes where the wires are revolved with the object of preventing inductive disturbance. It is usually stipulated that branch wood shall not be used for making arms, and that the arms shall not contain the centre pith of the tree. It is not practicable to inject creosote into arms satisfactorily, and the practice followed by the Post Office, therefore, is to pickle them in the following mixture :—

40 gallons of green oil (bye product of coal tar distillation).
6 gallons boiled linseed oil.
4 lbs. zinc chloride.

The pickling process consists of submerging the arms in the above mixture for two periods of twenty-four hours each, the mixture being kept at a temperature of 200° F. during the time by means of steam coils. The table on opposite page shows the average strength of some of the woods referred to above.

The cross-section of the arm was in all cases $2\frac{1}{2} \times 2\frac{1}{2}$ inches, and the leverage 21 inches.

The figures in column A were obtained from arms tested as simple cantilevers, that is to say, the arm was bolted to the equivalent of a terminal pole, and a straight pull was applied to a stirrup passing through a spindle hole 21 inches from the pole bolt hole. Fig. 38 is a photograph showing an arm in the testing machine ready for test. The figures in column B were obtained from arms

tested under practical conditions, that is, the arms were bolted to the equivalent of a terminal pole and an insulator was fitted to a spindle 21 inches from the pole bolt hole, and a pull applied at the groove of the insulator. In this latter test there is a torsional stress in addition to the cantilever stress, and the arms in all cases broke by splitting along the middle of the arm, due to the torsional stress. It will be noticed that the figures in column B are in most cases about 66 per cent. of those in column A. The arms were tested as received, and the moisture ascertained after testing. It is probable that somewhat higher results would have been obtained if the moisture had been lower, say, in the neighbourhood of 15 per cent.

A few years ago a practical trial was made of teak for telegraph arms, but the teak used for the purpose had had its natural oil

Kind of Wood.	A.	B.	Moisture per Cent.
	lbs.	lbs.	
Karri . . .	1825	1204	21 to 26
" . . .	1691	1052	"
" . . .	2112	896	"
" . . .	1590	896	"
Spotted Gum . .	1792	1036	20 to 26
" " . .	1736	996	"
" " . .	1732	1103	"
" " . .	2083	1187	"
" " . .	1534	840	"
Ironbark . .	2256	1344	16 to 20
" . . .	2240	1064	"
" . . .	1876	1344	"
Jarrah . . .	1136	896	16
" . . .	1299	756	"
English oak . .	1327	1120	20 to 26
" " . .	1220	756	"
American oak .	1108	980	Not determined
Russian oak . .	1400	784	" "
Austrian oak . .	1517	1092	" "

extracted before the trees were felled, and it is perhaps not surprising, therefore, that the trial was unsatisfactory, the arms proving to be both weak and brittle.

Ladders.—Spruce (white deal) is regarded as the best wood for the stiles of ladders, and since it has little or no sapwood it is well suited for this purpose, and on this account is superior to red fir (*Pinus Sylvestris*). Preferably the bark should not be removed until the spar is required for conversion into stiles, which are obtained by sawing it along a diametral plane. The fibre should run parallel to the length of the stile, and not deviate to any appreciable extent, otherwise the ladder will twist after it is brought into use, and to ensure safety it will require to be wedged at the bottom to cause it to stand firm every time it is used. The direction of the fibre can be checked by noting the course taken by any small drying shakes that may be present, or by lifting a thin splinter with the point of

a knife and skilfully raising it for 6 or 8 inches. It requires a little practice to do this successfully, and the easiest method is to press the splinter on one side while the point of the knife prises up the other. The centre line of the rung ends should be accurately in the middle of the stile, because in this position the holes have least effect in reducing the strength of the stile. Ladders are intended to bear the weight of one man only, and not more than one, but it is fair to the maker of the ladder to insist that the ladder shall bear this weight in its most flexible position, viz., when it is supported at the two ends in a horizontal plane and the load applied with an oscillating movement in the middle of the ladder; in other words, stand on the ladder and gently sway it up and down. If a ladder fails under a test of this kind it is a happy circumstance, because otherwise it might if brought into use without test have caused a serious accident.

Rungs.—The rungs are generally made from cleft oak, that is to say, the oak is split along the grain, leaving the fibres continuous and parallel to the edge. This is the best method of getting out rungs of ladders and spokes of wheels. It is frequently stipulated that turned rungs shall not be used because of the liability to produce turned rungs with the grain running obliquely to the length of the rung, with consequent weakness. The rungs should be approximately elliptical in section, with the greatest diameter parallel to the length of the stile, so that the ends which are housed in the stile will prevent the rung from turning, and the rung will be in its strongest position to bear a load. Good white lead ground in linseed oil should be used for housing the rungs, and not glue. The latter is, of course, deleteriously affected by moisture. For pole line work iron wire rungs are fitted at the top and bottom of stout ladders less than 36 feet in length. The Post Office specification for these rungs is as follows: "Four No. 8 galvanised iron wires each about 7 feet long are passed through the $\frac{3}{8}$-inch holes in the ends of the stiles, so that equal lengths project on either side of the ladder. The wires on each side are then wrapped tightly round the stiles—two wires one and a half turns in one direction, and the other two one and a half turns in the reverse direction. The four wires at one stile are wrapped tightly side by side round the centre wires to within 2 inches of the other stile, two of these wires being then unwrapped again to within 2 inches of the first stile. The wires from the opposite side are then wrapped similarly in the gaps left, four side by side for 2 inches, two for the remainder of the distance. The ends to be cut and pressed home so as to make a neat job. The wire rungs to have a dip of 2 inches in the middle between the stiles."

The stiles should be tied together with $\frac{5}{16}$ inch round galvanised iron tie-rods, and fitted with galvanised iron washers at each end. The washers should be slightly countersunk on the inner edge, the rods well riveted over and left smooth and as flush as possible and free from rough edges. One tie-rod should be fitted under the bottom rung, one under the second rung from the top, and others at approxi-

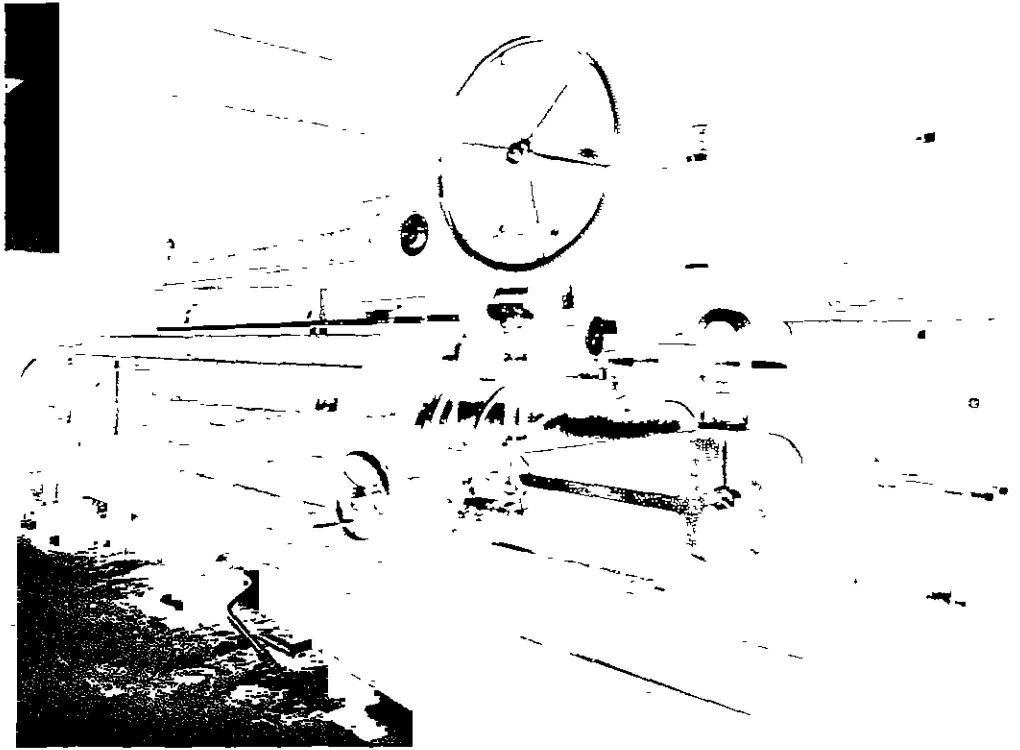


FIG. 38.—Buckton 30-ton Testing Machine at Studd Street, London, Testing Branch.

mately equal intervals, making in each case the total shown in the following table, which is extracted from the Post Office specification. The pitch of the rungs is 10 inches, but builder's ladders are usually 8 inches.

No. of Rounds.	Length of Ladder.		Number of Tie-Rods.	Dimensions of Stiles. Bottom.	Dimensions of Stiles. Width ⅔ Way Up.	Dimensions of Stiles. Top.	Width Inside Stiles. Bottom.	Width Inside Stiles. Top.	Dimensions of Middle of Round. Bottom.	Dimensions of Middle of Round. Top.
	LIGHT.									
	ft.	ins.		ins.	ins.	ins.	ins.	ins.	ins.	ins
12	11	6	3	3 × 1⅝	2⅞		11			
18	16	6	4	3¼ × 1⅝	3	2¾ × 1⅝	11½			
24	21	6	5	3½ × 1¾	3⅛		12	10	1½ × 1¼	1¼ × 1⅛
30	26	6	7	4 × 2	3¼	3 × 1½	12¼			
36	31	6	8	4 × 2	3⅜		12½			
	STOUT (below 36 feet long).									
12	11	2	4	3¾ × 1⅞	3⅜		12	10½	1½ × 1¼	1¼ × 1⅛
18	16	2	5	4 × 2	3½		12			
24	21	2	6	4¼ × 2⅛	3⅝	3 × 1½	13			
27	23	2	6	4¼ × 2⅛	3⅝		13	11	1⅝ × 1⅜	1½ × 1¼
30	26	2	7	4½ × 2¼	3¾		13			
36	31	2	8	4¾ × 2⅜	3⅞		13½			
	STOUT (above 36 feet long).									
42	36	6	10	4⅞ × 2⅜	3⅞					
48	41	6	11	5 × 2½	4	3 × 1½	13½	11	1⅝ × 1⅜	1½ × 1¼
54	46	6	12	5 × 2½	4					

APPENDIX TO CHAPTER IV

THE following is a brief description of the 30-ton Buckton Testing Machine shown in Fig. 38.

The power is obtained from a hydraulic accumulator which delivers water at 700 lbs. pressure to the hydraulic ram at the right-hand end of the figure. The pressure water valve is controlled by the long cranked lever near the middle of the base of the machine. This long lever enables the valve to be opened very gradually, and the traverse of the machine can be varied as regards speed within wide limits. The ram pushes forward the frame of the machine,

which is keyed to a cross-head by means of keyways and keys, two of which are shown in position near the left-hand end of the figure. Another cross-head, which can be seen in the figure above and a little to the right of the cranked lever, is carried on two large screws that run the whole length of the machine, and operate at the right-hand end of the machine a bell-cranked lever which is connected to the weighing mechanism. The unscrewed portions of the two screws can be seen in the figure, one just behind the pressure gauge and the other just below the bell-cranked lever. These two screws, at the right-hand end of the figure, are connected by a cross-piece which bears against a knife edge, thus communicating the force applied to the specimen to the weighing mechanism. The weighing mechanism consists of a bell-cranked lever, at the narrow end of which a link is connected and carries the load to the top beam, where the two knife edges can be plainly seen close to the lowest two spokes of the weight-driving large wheel. The back knife edge on the beam is 10 inches from the front one; the length of the long arm of the bell-cranked lever is 30 inches and the short arm 3 inches. The load on the screws is consequently transmitted to the beam, which reads the load direct by means of the steelyard and travelling vernier. The weight on the beam is subdivided, so that the steelyard readings have to be multiplied by the number of hundredweights which are attached to the travelling carriage on the beam. With 1 cwt. on the carriage the steelyard reads from 0 to 5 tons, and by means of the vernier any load between this range can be read to an accuracy of about 1 lb. Weights are provided so that a total load of 30 tons can be read on the steelyard when 6 cwts. are on the carriage and the carriage is at the far end of its traverse. The figure shows the machine fitted with a special bracket for cantilever testing. The bracket is keyed to the frame of the machine by the first of the double keys. The double key at the end of the machine keys a cross-head to the frame of the machine, which for this test is not in use. The sample under test is a wood telegraph arm, which is bolted through the arm bolt hole to the special bracket. The load is applied by means of a stirrup, which passes through the outside spindle hole of the arm. The stirrup is connected by means of a doubled rope to the cross-head, which is screwed to the two straining screws. The frame of the machine and the attached special bracket are pushed out by the hydraulic ram, and the doubled rope communicates the pull to the fixed cross-head and straining screws. The pull is kept balanced on the steelyard by means of the chain wheel, which drives the weight carriage. When the sample breaks the beam drops and the breaking load is read from the steelyard. The frame of the machine is drawn back to its starting position when the exhaust valve of the hydraulic ram is opened, by a heavy weight chained to the frame and accommodated in a square pit below the ram. The lever operating the exhaust valve is seen on the right of the two water pipes near the end of the bell-cranked lever. For ordinary tension tests of bolts, rope, etc.,

the sample is gripped by dies which fit into dieholders in the two cross-heads. The machine is designed for testing long samples, and will test a 1-inch stay rod fitted with a stay tightener bow complete. A wide bracket is bolted to the front end of the hydraulic ram, so that samples can be tested in compression between this bracket and the cross-head attached to the straining screws. This cross-head can be moved to any part of the frame by means of the gearing at the far end of the machine, which consists of an idle wheel which operates two spur wheels keyed to the straining screws which carry the cross-head. The beam is also connected to a worm gear on the other side of the machine to that shown in the figure, which provides facilities for making torsion tests. The accuracy of the machine can be checked by means of dead loads applied to a bracket, which is attached when necessary to the end of the machine shown at the right hand of the figure. The bracket is supported on a knife edge and bears against a steel rod which passes through a hole in the frame and bears against the first knife edge of the bell-cranked lever. The balance weight at the end of the beam is adjustable by means of the screws shown at the top of the weight and the end of the beam. Suitable volute and helical springs are fitted to absorb the shock when the sample breaks. The pressure gauge shows the water pressure in the ram, and indicates that the load is being applied. In some tests the load is applied so slowly that the pressure gauge is the most ready indication that the supply valve is open. This machine is installed at Studd Street Testing Branch. A similar machine, except that it is driven electrically, is in use at Birmingham Testing Branch. The electrical drive does not provide such a large range of speed for the traverse of the frame of the machine, but the same speed of loading different samples can be more accurately arranged with the electrical drive, and in this respect it possesses obvious advantages.

CHAPTER V

COPPER

COPPER, in addition to occurring as native copper, that is, pure copper, is found in a large number of ores as oxide, basic carbonate and sulphide, and also in combination with iron as copper pyrites. Among the most important ores are :—

Chalcocite (cuprous sulphide, Cu_2S).
Cuprite (cuprous oxide, Cu_2O).
Malachite (basic carbonate, $CuCO_3 . Cu(OH)_2$).
Azurite (basic carbonate, $2CuCO_3 . Cu(OH)_2$).
Covellite (cupric sulphide, CuS).
Enargite (arsenical pyrites, $3Cu_2S . As_2S_3$).
Bornite (cupriferous pyrites, Cu_3FeS_3).
Chalcopyrite (cupriferous pyrites, $CuFeS_2$),

but the list is far from complete. Until the middle of the last century South Wales held the foremost place in the smelting of copper from its ores, but to-day America produces the bulk of the copper placed on the market, especially that known as H.C., or High Conductivity copper. The Welsh method of smelting copper pyrites required at least six, and sometimes eight, distinct processes to produce the final product, and they may be popularly described as follows: (1) Mixed ores, selected so as to contain about 10 per cent. of copper, the composition of the remainder consisting of iron, sulphur, and sand, were roasted or calcined in a reverberatory furnace, thereby expelling part of the sulphur and partially oxidising the metals; (2) the roasted ores were next melted in a reverberatory furnace, which had a lining of silica (sand), which caused part of the iron oxide to unite with the silica and form a fusible slag. This slag floated, and was allowed to overflow to separate it from the remainder, which consisted principally of ferrous and cuprous sulphides. The product of this process was known as Coarse Metal, and contained about 30 per cent. of copper; (3) the hot coarse metal was then granulated by being run into water and afterwards put into a reverberatory furnace and again calcined. A further amount of sulphur was thereby expelled and the metals partially oxidised; (4) the calcined coarse metal was again melted, with the addition of special slags obtained from the subsequent processes. The bulk of the iron now passed into the slag, which was allowed to overflow

and the remainder consisted of *white metal*, containing about 70 per cent. of copper; (5) the white metal was again melted in a reverberatory furnace of special design to admit of better oxidation of the charge, and the slag formed removed periodically. The remaining sulphur was thereby burnt off as sulphur dioxide, and the residue was tapped into sand moulds. The escape of the sulphur dioxide in the final processes gave the castings a blistered appearance, and the copper from this stage of the process was known as "blister" copper; (6) the "blister" copper was again melted in a reverberatory furnace for the removal of the remainder of the impurities which were still present. The metal was melted as rapidly as possible and exposed to a rapid current of air to oxidise the impurities, which oxidise more readily than the copper, and pass into the slag, which was skimmed off from time to time. When the copper began to oxidise samples were taken and cast into the form of briquettes and from the fracture a good indication of the stage of the process was obtained. When the process was considered at a satisfactory stage the small amount of oxide of copper remaining was reduced by the addition of charcoal or anthracite, and finally by stirring the molten metal with green wood poles. The final stages of the poling process were controlled by testing small briquettes of the copper taken from time to time. If the briquettes gave a brick-red fracture the copper was said to be "dry" and required more poling. When a lighter coloured fracture was obtained on testing, and the fracture was fine grained, the metal was considered satisfactory, and was cast into iron moulds. Although considerably modified and improved these processes are still followed to a considerable extent in modern practice.

The copper obtained from Spain is produced by a wet process. The bulk of the ore is chalcocite (Cu_2S), which when exposed for a long period of time to air and water, undergoes a series of chemical changes, subsequently producing copper sulphate ($CuSO_4$). The ore is broken up into lumps about the size of large pebbles and built up into huge heaps of about 100,000 tons. The heap is intersected with a network of air flues to promote oxidation, and water is from time to time run on the top of the heap. The copper liquor which drains from the heap is conveyed to precipitation vats, and the copper is thrown down by treating the liquor with scrap iron. The precipitate or cement copper is subsequently washed in a special launder with a strong jet of water, and is divided into three grades as it settles at different distances from the jet. "No. 1 precipitate" is the first to settle, and contains the highest percentage of copper—generally about 94. "No. 2 precipitate" contains about 92 per cent., and "No. 3 precipitate" is much lower. Nos. 1 and 2 are shipped to England for refining. No. 3 is dealt with locally in blast furnaces. The bulk of the Spanish ore is owned by the Rio Tinto Company. As a result of a long series of tests in 1878 on this company's ore, John Hollway, an Englishman, introduced a method of pyritic smelting on the lines of the Bessemer steel-making process,

but taking advantage of the fact that the sulphur in the ore is combustible and can be used as a source of heat in metallurgical operations. In Professor H. C. H. Carpenter's Cantor Lectures on "The Metallurgy of Copper," delivered before the Royal Society of Arts in December, 1917, he says :—

"In the last two decades of the nineteenth century, when the United States of America became the largest producer of the metal, very great advances were made in the technique of copper smelting and refining. These have continued during the opening years of the twentieth century, and to-day the position of America is one of unchallenged—though I do not say unchallengeable—supremacy. These advances include the following developments :—

"(1) Great improvements in mining and ore-dressing operations (mechanical concentration).

"(2) The use of mechanically-rabbled roaster furnaces.

"(3) The manufacture of sulphuric acid both from blast furnace and roaster gases.

"(4) The blast roasting and sintering of sulphide fines.

"(5) The practical application of the pyritic smelting principle to suitable raw ores and to practically all copper mattes.

"(6) An enormous increase in the capacity and output both of blast and reverberatory furnaces.

"(7) The recovery of metal values from the furnace waste gases.

"(8) The adoption of electrolytic refining, followed in many cases by furnace refining, with the recovery of precious metal values in the copper which more than suffice to pay for their extraction. And most recently of all :—

"(9) The application of either leaching or flotation processes, or both, to low-grade ores, tailings, etc. The effect of all these improvements has been to bring within the scope of practical economic development ores of lower and lower grade, and thus to lengthen the life of existing mines and to include others which even ten years previously were incapable of beneficiation. It must not be forgotten, however, that British workers have had an important share in these developments. At most of the great smelters in the new districts in America, now the chief seat of the industry, Welsh furnacemen are still to be found."

Professor Carpenter gives a very interesting technical description of the works of the famous Anaconda Copper Mining Company, and the reader is recommended to read the lectures (which are published at a shilling by Messrs. Clowes & Sons), as they give a very graphic account of the wonderful organisation and lay out of this Company's huge plant and premises.

The copper obtained from the electrolytic process is practically pure (99·95 per cent.), but it is not tough enough for industrial use, and the cathodes are not of a suitable shape. The copper is consequently remelted and cast into wire-bars about 4½ inches square and about 6 feet long. These wire-bars are used in the manufacture of telephone and telegraph wire. The bars are heated to a suitable

temperature and passed through a series of grooved rolls until the diameter is reduced to about half an inch. As the copper is exposed to the air during the rolling process, the surface oxidises and when cold the half-inch rod is found to have a coating of black copper oxide. This oxide is removed by submerging the rod in a vat of dilute sulphuric acid, and the resulting bright copper rod is ready for drawing down into wire. Fig. 39 is a drawing of a draw plate used for this purpose. It consists of a hard steel plate with a small conical hole through which the wire passes, the hole having a diameter at its exit slightly smaller than the diameter of the rod. The end

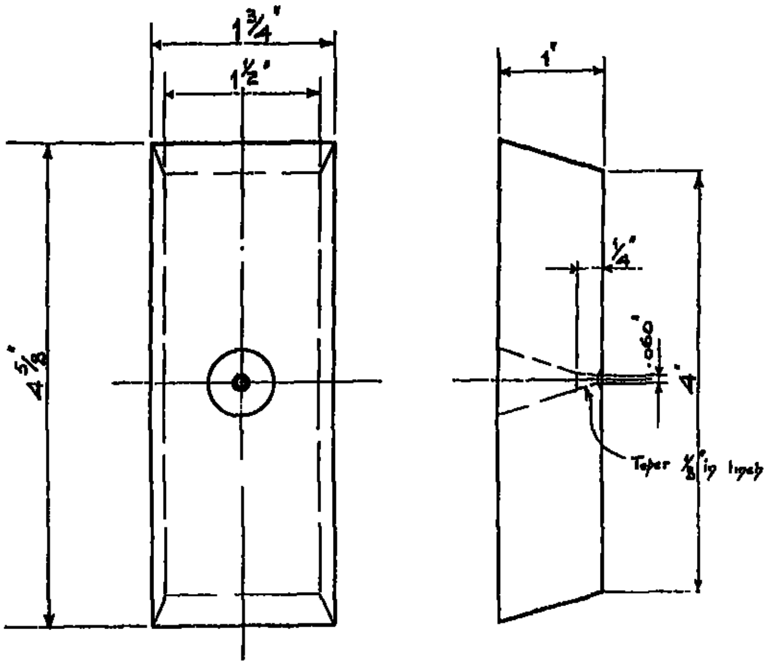


FIG. 39.

of the rod is filed down sufficiently to admit of its passing through the hole, and is then gripped by a vice attached to a power-driven swift or drum. The whole of the rod is pulled through the hole, and its diameter is reduced accordingly. The metal being thoroughly annealed and soft at the commencement of the process, it is possible to pass the rod through a large number of draw plates, each succeeding hole being slightly smaller in diameter than the preceding hole, without the copper being re-annealed. For wires of small diameter, say up to 36 mils, the hole in the final draw plate is a jewelled hole. The jewel employed is usually a diamond which has been pierced or bored to the exact diameter required. Diamond drawn wire is

usually quite circular in section and of uniform diameter along its length. Wire finished on a steel draw plate is seldom truly circular in section, and hard drawn wire varies slightly in diameter, due to the gradual wear of the hole in the steel draw plate. The change in tensile strength that takes place, due to the drawing process, is well illustrated in Fig. 40, which is taken from Mr. W. E. Alkins' paper on "The Effect of Progressive Cold Work upon the Tensile Properties of Copper," read before the Institute of Metals in September, 1918. Mr. Alkins drew attention to the fact that his tests

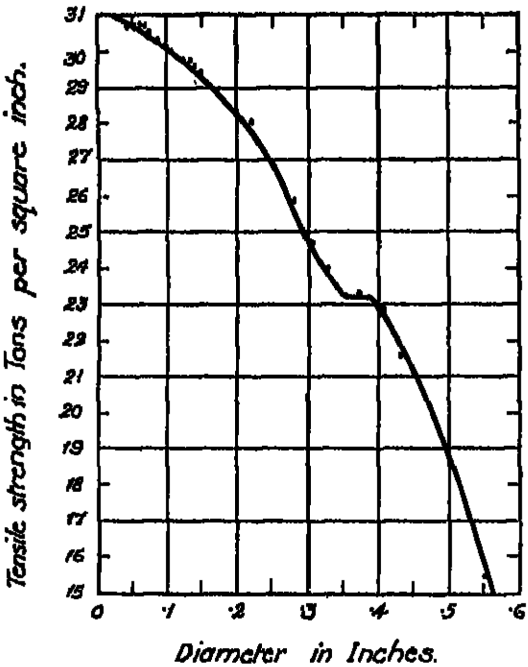


FIG. 40.

showed that "there is one stage in the drawing at which a reduction in area of almost 10 per cent. (from ·372 to ·348 inch diameter) is accompanied by no change in tensile strength." If the drawing down from the rod to the last diameter (between twenty and thirty draws) was done without annealing at any stage, the change of slope referred to is certainly a phenomenon which has not so far been previously reported, and it is difficult to explain. The tensile strength of annealed copper wire is not much above 15 tons per square inch, and the wire used for internal wiring and underground cable work has generally a tensile strength of this order.

Hard Copper Wire.—For overhead telegraph and telephone construction the line wire is hard drawn, the tensile strength being from about 28 to 30 tons per square inch. The following table is taken from the Post Office Specification for hard copper wire:—

TABLE FOR HARD COPPER WIRE

Weight per Statute Mile.			Approximate Equivalent Diameter.			Minimum Breaking Stress of Standard Weight.	Minimum Number of Twists.	Maximum Resistance per Mile of Standard Weight at 60° F.	Weight of each Piece (or Coil).	
Required Standard.	Minimum.	Maximum.	Required Standard.	Minimum.	Maximum.				Minimum.	Maximum.
lbs.	lbs.	lbs.	ins.	ins.	ins.	lbs.		Standard ohms.	lbs.	lbs.
800	784	816	0·2237	0·2215	0·2259	2400	In 6 ins. 15	1·0984	100	140
600	588	612	0·1937	0·1918	0·1956	1800	20	1·4649		
400	392	408	0·1582	0·1566	0·1598	1250	25	2·2017		
300	294	306	0·1370	0·1356	0·1384	945	30	2·9413		
200	196	204	0·1119	0·1108	0·1130	640	In 3 ins. 20	4·4206	75	140
150	147	153	0·0969	0·0959	0·0979	490	25	5·8999		
100	98	102	0·0791	0·0783	0·0799	330	30	8·8584		

The wire should be free from all defects such as scale, spills, splits, inequalities, etc., and be approximately circular in section, smooth, uniform in quality, and pliable. The wire should not be brazed or otherwise jointed together, but each piece bound up in a separate coil.

Wrapping Test.—The wire should bear without breaking the following wrapping test. The wire is—

(1) Bent into a U shape and the bend gripped in a vice.

(2) One leg of the U wrapped on the other leg in a close helix of seven complete turns.

(3) Six of these turns unwrapped; and

(4) The six turns again wrapped on in a close helix in the same direction as in (2).

Every piece is generally tested at both ends for tensile strength, wraps, and twists. Two or three per cent. of the coils are tested electrically.

Twisting Test.—The twists are made as follows: The wire is gripped by two vices, one at each end of the length of wire stipulated, and one vice is made to rotate at a speed not exceeding one revolution per second, the torsion being shown by means of an ink mark, which forms a helix on the wire during the test. The full number of twists stipulated must be distinctly visible between the two vices. Fractions of a turn are not taken into account.

Tensile Test.—The breaking load of the wire when tested as follows and corrected to standard weight should not be less than

the value given in the table. A lever testing machine of which the accuracy can be easily checked, and the machine adjusted if necessary, is used. The test sample as cut from the coil is placed in the machine without being straightened or prepared in any way before testing. The machine is set at nine-tenths of the minimum breaking load, and the sample lifts this, the remaining part of the load being added steadily until the sample breaks. The time occupied in applying the final one-tenth should be as nearly as possible 5 seconds, and the total time from the application of the load to the break should be approximately 10 seconds.

Inspection.—Each coil of wire should be carefully examined for splits, spills, scale, and other defects of the surface, and all bad places cut out if near the ends of the coil, or the coil should be rejected if the defects are in the middle of the coil.

Electrical Test.—The length of the test piece for electrical resistance should be not less than one-thirtieth of a mile. The temperature coefficient is 0·0022221 per degree F., and the formula for temperature correction is $R_{60} = \frac{R_T}{1+\alpha(T-60)}$ where $\alpha = \cdot 0022221$. R_T = resistance at temperature T degrees, and R_{60} = resistance at 60° F. If R be the resistance *per mile* of the test piece, W the weight in pounds per mile of the test piece, K the *required standard* (see table) in pounds per mile, and C the temperature coefficient required to bring the result to 60° F., then the product

$$R \times C \times \frac{W}{K}$$

should not exceed the value given in the ninth column of the table.

$$C = \frac{1}{1 + \alpha(T - 60)}.$$

An example is given later of the method used in calculating the resistance.

Eye.—The eye of the coil should be not less than 19 inches, and not more than 20 inches in diameter, in order to fit Post Office swifts and drum-barrows.

Weighing and Packing.—Each coil of wire should be weighed and the weight recorded on a label and attached to the coil.

Each coil of approved wire is usually wrapped in canvas and despatched for delivery in casks or cases.

Bronze Wire.—Similar tests are applied to bronze telephone wire. The table on opposite page is taken from the Post Office Specification.

It is important to remember that hard drawn wire, whether copper or bronze, should be handled carefully. Sharp bends or kinks are liable to be the cause of a breakage after the wire is erected.

TABLE FOR BRONZE WIRE

Weight per Statute Mile.	Approximate Equivalent Diameter.			Minimum Breaking Stress of Standard Weight.	Minimum No. of Twists in		Maximum Resistance per Mile of Standard Weight at 60° F.	Weight of each Coil.		Diameter of Eye of Coil.	
Required Standard.	Required Standard.	Minimum.	Maximum.		3 ins.	6 ins.		Minimum.	Maximum.	Minimum.	Maximum.
lbs.	inch.	inch.	inch.	lbs.			Standard ohms.	lbs.	lbs.	ins.	ins.
300	·137	·135	·139	1320	—	12	6·07	100	140	19	20
150	0·097	·095	·098	700	8	—	12·14	75	140	19	20
100	·079	0·78	·080	485	12	—	18·2	60	140	19	20
70	·066	·065	·067	345	15	—	26·0	50	140	19	20
40	·050	·0495	·0505	200	20	—	45·5	20	30	9	10

Details of Electrical Test.—In taking the electrical resistance it is necessary to use either a slide wire bridge and standard resistance coil of approximately the same value as the resistance of the length of wire to be tested, or a decimal plug bridge. The third arm of the latter is provided with resistances advancing in steps of 0·1 ohm, and the ratio arms are 1, 10, and 100 ohms. The latter bridge is in most general use. The battery is either a 2-volt accumulator or a good dry cell, and the galvanometer a sensitive one of the reflecting type. The wire is wound on a grooved wooden cylinder provided with terminal clips, arranged so that exactly one-thirtieth of a mile of wire is taken for the test, different clips being used for the several sizes of wire, to allow for the effect of the change in length of a convolution, due to the diameter of the different types of wire tested. Allowance must be made for the resistance of the wire joining the bridge to the coil under test. An accurate thermometer is used to ascertain the temperature at the time of testing.

The following example will illustrate the method of calculating the "resistance per mile of standard weight at 60° F." of 400 lbs. wire.

Let the resistance of the testing leads from the wire under test to the bridge be 0·005 ohms; the resistance of the wire under test together with the leads be 0·077 ohms; the temperature of the wire during test be 65° F.; the length of the wire exactly one-thirtieth of a mile, and the weight of this length 13·56 lbs. Then resistance per mile of standard weight at 60° F.

$$= \frac{(R - R_l) \times 30 \times W \times 30}{W_s \times (1 + a(T^\circ - 60^\circ))}.$$

where—

R is the total resistance shown on the bridge.
R_l is the resistance of the leads.
W is the weight of the piece in pounds.
W_s is the standard weight per mile in pounds.
a = ·0022221.
T = temperature in degrees F. of test sample during the test.

Inserting in this formula the values given above, we have Resistance per mile of standard weight at 60° F.

$$= \frac{(\cdot077 - \cdot005) \times 900 \times 13\cdot56}{400 \times 1\cdot0111} = \frac{878\cdot7}{404\cdot44} = 2\cdot173 \text{ ohms.}$$

The temperature coefficient for the bronze wire used by the Post Office is ·001016 per degree F., and the corresponding value of C is $\frac{1}{1 + \cdot001016(T^\circ - 60^\circ)}$. This coefficient is based on a conductivity for the bronze of 45·8 per cent. of annealed high conductivity copper. The actual conductivity of the bronze, based on the specified figure for resistance, is 47·2 per cent., but as the former figure has been in use for some years, and the difference between the two coefficients is negligible, it is retained. The temperature coefficient of bronze wires of different conductivities can be obtained from the following formula :—

$$R_{60^\circ} = \frac{R_{t^\circ}}{1 + 0\cdot0022221 \times \frac{K}{100}(t^\circ - 60^\circ)}$$

where K is the percentage conductivity of the bronze wire under consideration. The actual temperature coefficient of samples of bronze wire of 50 per cent. conductivity has recently been measured for temperatures between 46° F. and 100° F. in the Post Office laboratories, and has been found to agree within 1 per cent. with the above formula. The formula is derived from Matthiessen's law that "the percentage of decrement in the conducting power of an impure metal between 0° C. and 100° C. is to that of the pure one between 0° C. and 100° C. as the conducting power of the impure metal at 100° C. is to that of the pure one at 100° C." (" Phil. Trans.," p. 167, 1864).

Lead Covered Paper Core Cables.—The wire used in these cables is annealed copper. The weight diameters and resistances of the wires most frequently used by the Post Office are shown in the following table :—

Weight per Mile of Conductor.	Diameter.		Maximum Resistance per Statute Mile at 60° F.
	Minimum.	Maximum.	
lbs.	Ins.	Ins.	Standard ohms.
6½	·0195	·0205	135·115
10	·0245	·0255	87·825
20	·0350	·0360	43·912
40	·0495	·0505	21·956
70	·0655	·0665	12·546
100	·0780	·0800	8·782
150	·0960	·0980	5·855
200	·1105	·1135	4·391

For multiple twin cables to provide for resistance balance, the Post Office specifies that "the two conductors of each pair in each length of cable shall be cut from the same coil of wire, and shall be obtained by halving a continuous length of wire." No brazed or other points are allowed in the wire, except those necessitated by breakages during the stranding processes. These joints are made by scarfing the wire and brazing, and then covering the joint with a double wrapping of fine wire and soldering the ends of the wrapping. The conductors are insulated by (*a*) a spiral wrapping; (*b*) a longitudinal wrapping; or (*c*) a combination of spiral and longitudinal wrappings of paper at the choice of the manufacturer. The thickness of the paper should be uniform and not less than 2½ mils, and a strip 1 inch in width should support a weight of 4 lbs. for each mil of thickness. The paper should be uniform in texture, long-fibred, and free from metallic particles and deleterious substances.

The small cables (distribution) up to 15 pairs have each conductor covered with two wrappings of paper, the first of which is longitudinal and the other spiral, so as to enclose completely the conductor. The larger cables have only one wrapping of paper. For main and composite (containing more than one size of conductor) cables the method of twinning is as follows: Two conductors insulated with paper of the same colour, but one wire being lapped with red and the other with white string are uniformly twisted together to form a pair. The lays of the conductors forming the pairs, and the colours of the papers used, are shown in the following table:—

Weight per Mile of Conductor.	Colour of Insulating Paper and Length of Lay in Inches.			
	(*a*) Orange. (*f*) Red.	(*b*) Blue.	(*c*) White.	(*d*) Green.
lbs. 6½, 10	4	5	6	7
20, 40	5	6	7	8
70	6	7	8	9
100	7	8	9	10
150	9	10	11	12
200	10	11	12	13

The insulated pairs are then stranded into a compact and symmetrical cable, the order of the pairs in stranding being as follows: In cables having one pair as a centre, the centre pair will have the lay (*a*) (see table); those with two pairs as a centre, one pair will be (*a*) and the other (*d*); those with three pairs as a centre, one pair will be (*a*), one (*b*), and the third (*d*); those with four pairs as a centre, the lays are (*a*), (*b*), (*c*), and (*d*); whilst the sequence of lay in the layers round the centre will be in accordance with the following table:—

No. of Pairs in Layers.		Sequence of Colours and Lays.
6, 9, etc. .	. 6 + 3*n*	*a b c, f b c, f b c, etc.*
7, 10, 13, etc.	. 7 + 3*n*	*d a b c, f b c, f b c, etc.*
8, 11, 14, etc.	. 8 + 3*n*	*d f b c, d a b c, f b c, f b c, etc.*

In composite cables the pairs are stranded in order of weight, the heaviest gauge conductors being in the centre of the cable.

The general arrangement of centre and layers of the various types of main cable other than composite are shown in the following table :—

ORDER OF STRANDING

Number of Pairs of Conductors in Cable.	Number of Pairs in Centre and Surrounding Layers.																	
	Centre.	1st.	2nd.	3rd.	4th.	5th.	6th.	7th.	8th.	9th.	10th.	11th.	12th.	13th.	14th.	15th.	16th.	17
2	2																	
4	4																	
8	1	7																
10	2	8																
15	4	11																
25	3	8	14															
35	1	6	11	17														
50	3	9	16	22														
75	3	9	15	21	27													
100	2	7	13	19	26	33												
125	1	6	12	18	24	29	35											
150	3	9	15	21	27	34	41											
200	4	10	16	22	28	34	40	46										
250	3	9	15	21	27	34	40	47	54									
300	3	9	15	21	27	33	39	45	51	57								
400	1	6	12	18	24	30	36	42	48	54	61	68						
500	2	8	14	20	26	32	38	44	50	56	63	70	77					
600	3	9	16	22	28	34	40	46	52	58	64	70	76	82				
800	4	10	16	22	28	34	40	46	52	58	64	71	78	85	92	100		
1000	4	10	16	22	28	34	40	46	52	58	64	70	76	82	89	96	103	11

An open spiral wrapping of insulating paper is laid on between the centre and the first layer and over each successive layer. The direction of the stranding of the centre, when it consists of more than a single pair of wires, is left-handed, and the first and succeeding layers are alternately right- and left-handed. A final spiral wrapping of at least one thickness of the insulating paper is added between the outer layer and the lead sheath.

For small **distribution cables** (up to 15 pairs) the twinning and stranding are arranged as follows: Two insulated conductors, one covered with red paper and one with white, are uniformly twisted together to form a pair, and lapped with coloured thread, the various colours of the thread and the corresponding length of lay of the wires in the pairs and the order of stranding being shown in the following table :—

TWINNING

Colours of Thread Round Pairs.	Length of Lay of Wires in Pair.	Pair Letter.	Colours of Thread Round Pairs.	Length of Lay of Wires in Pair.	Pair Letter.
	Ins.			Ins.	
White . . .	3	*a*	White and green .	5	*j*
Green . . .	4	*b*	White and blue .	6	*k*
Blue . . .	5	*c*	White and black .	4	*l*
Black . . .	6	*d*	Green and blue .	5	*m*
Green and red .	4	*e*	Green and black .	6	*n*
Blue and red .	5	*f*	Blue and black .	4	*o*
Black and red .	6	*g*	Red . . .	5	*p*
White and red .	4	*h*			

STRANDING

Size of Cable.	The Pairs to be Used in Centre and Surrounding Layers.	
	Centre.	Surrounding Layers.
Pairs.		
1	*a* *	
2	*a*, *b*	
3	*a*, *b*, *c*	
4	*a*, *b*, *c*, *d*	
7	*a*	*b*, *c*, *d*, *e*, *f*, *g*.
8	*a*	*b*, *c*, *d*, *e*, *f*, *g*, *h*.
10	*a*, *b*	*c*, *d*, *e*, *f*, *g*, *h*, *j*, *k*.
15	*a*, *b*, *c*, *d*	*e*, *f*, *g*, *h*, *j*, *k*, *l*, *m*, *n*, *o*, *p*.

* *Note.*—In the case of 1 pair cable, no distinguishing thread need be included.

The length of lay (pitch of the helix) of the coloured thread should not exceed half that of the wires in the pair which it surrounds.

The stranded conductors forming the cable should be covered over all with two thicknesses of paper laid on spirally in opposite directions, so as effectively to prevent contact between the conductors and the lead sheath.

For **multiple twin** cable the cores of the cable are formed as follows: Two wires insulated with paper of the same colour, but one wire being lapped with red and the other with white string are uniformly twisted together to form a pair. The length of the lay is shown in the table on page 84.

Each pair is lapped with white string, the lapping being in the opposite direction to the lay of the pair, and the length of the lay of the string lapping being not more than half that of the pair. Two of these pairs are then uniformly twisted together to form a 2-pair core, with a lay in accordance with the following table. Each 2-pair

Weight per Mile of Conductor.	Approximate Length of Lay in Inches and Colour of Spiral Wrapping.							
	Pairs.				2-Pair Cores.			
	Red.	Blue.	White.	Green.	Red.	Blue.	White.	Green.
lbs.								
40	4	5	6	7	8	10	12	14
70	6	8	10	12	14	16	18	20
100 } 150 }	8	10	12	14	16	18	20	22
200	12	14	16	18	20	22	24	26

Note.—The pilot core on each layer should be covered with orange paper, and should be similar in all other respects to a red core.

core is covered with a spiral wrapping of paper having a distinctive colour in compliance with the following :

COLOUR SCHEME

Colour of spiral paper over 2-pair cores . .	R	W	B	G
Colour of paper on pairs composing the 2-pair cores	r.w.	b.g.	r.w.	b.g.

Note.—r = red ; w = white ; b = blue ; g = green. Small letters denote colours of paper on both wires of a pair.

Pilot cores covered with orange paper are provided in each layer. Except for the colour of the outer paper, these cores are similar in all respects to a red core. It will be noticed that the colour scheme provides for twinning red with white, and covering some with red and others with blue ; and twinning blue with green, and covering some with white and some with green. The above method of constructing 2-pair cores is not followed for 4-pair cores. In this case four pairs are stranded together to form one quad pair core.

The first layer is stranded with a right-hand lay and the succeeding layers alternate in direction.

A final spiral wrapping of at least one thickness of the insulating paper is added between the outer layer and the lead sheath.

Drying.—All cables after stranding are carefully and thoroughly dried at a temperature not exceeding 275° F.

Lead Sheath.—The cables are sheathed with new British or Colonial pig lead, applied at a temperature not exceeding 600° F. The sheath should form a perfectly continuous tube free from pin-holes, joints, mended places, and defects of any kind, and should be capable of withstanding an internal air pressure of 75 lbs. per square inch for three hours after equalising. Each length of cable containing more than 15 pairs, immediately after being sheathed,

should be submerged in water for twenty-four consecutive hours, the ends of the cable being, of course, sealed up before submerging.

For small distribution cables the external diameter and lead thickness are shown in the following table :—

Size of Cable.	6½ lbs. Conductor.		10 lbs. Conductor.		20 lbs. Conductor.	
	Maximum External Diameter.	Minimum Thickness of Lead.	Maximum External Diameter.	Minimum Thickness of Lead.	Maximum External Diameter.	Minimum Thickness of Lead.
Pairs.	in.	in.	in.	in.	in.	in.
1	—	—	·18	·039	·23	·042
2	—	—	·23	·042	·30	·046
3	—	—	·27	·045	·35	·051
4	—	—	·30	·047	·40	·054
7	—	—	·40	·065	·51	·065
8	—	—	·42	·065	·54	·065
10	·39	·065	·45	·065	—	—
15	·45	·065	·52	·065	—	—

For main cables containing only one size of conductor the external diameter and lead thickness are shown in the following table :—

Number of Pairs of Conductors.	6½ lbs.		10 lbs.		20 lbs.		40 lbs.	
	Maximum External Diameter.	Minimum Thickness of Lead.	Maximum External Diameter.	Minimum Thickness of Lead.	Maximum External Diameter.	Minimum Thickness of Lead.	Maximum External Diameter.	Minimum Thickness of Lead.
	ins.	in.	ins.	in.	ins.	in.	ins.	in.
2	—	—	—	—	—	—	·43	·065
4	—	—	—	—	—	—	·54	·065
8	—	—	—	—	—	—	·71	·070
10	·39	·065	·44	·065	·59	·066	·78	·072
15	·44	·065	·50	·065	·70	·069	·93	·077
25	·52	·065	·60	·066	·86	·075	1·16	·085
35	·59	·066	·68	·069	1·00	·080	1·34	·091
50	·68	·069	·79	·072	1·17	·085	1·58	·099
75	·81	·073	·94	·077	1·40	·093	1·91	·110
100	·91	·076	1·06	·082	1·60	·100	2·18	·120
125	—	—	—	—	—	—	2·43	·128
150	1·09	·082	1·27	·089	1·93	·111	2·64	·135
200	1·24	·088	1·45	·095	2·20	·120	—	—
250	1·37	·092	1·61	·100	2·45	·129	—	—
300	1·48	·096	1·75	·105	2·67	·136	—	—
400	1·70	·103	2·00	·113	—	—	—	—
500	1·88	·110	2·22	·121	—	—	—	—
600	2·05	·115	2·42	·128	—	—	—	—
800	2·34	·126	2·75	·139	—	—	—	—
1000	2·62	·134	—	—	—	—	—	—

For composite cables the mean internal diameter, lead thickness, and external diameter should be in accordance with the curve,

Fig. 41. When measured in any transverse section the lead thickness should be not less than 98 *per cent.* of that shown on the curve and corresponding to the necessary total space, and the external diameter should not exceed by more than ·025 inch 102 per cent. of the value for the mean external diameter obtained from the curve and corresponding to the necessary total space. The necessary total space is determined from the following :—

6½ lbs. conductors . . .	·0040	square inch per pair.
10 " " . . .	·0057	" "
20 " " . . .	·0140	" "
40 " " . . .	·0275	" "
70 " " . . .	·0475	" "
100 " " . . .	·0680	" "

The diameter of any composite cable should not exceed 3 inches.

The dimensions of the lead sheath of multiple twin cables are also based upon the curves in Fig. 41. The figures contained in the following table have been used in multiple twin cables actually manufactured, but they have not been standardised :—

Size of Cable. Number of Pairs.	Number of 2-Pair Cores.			
	Centre.	1st Layer.	2nd Layer.	3rd Layer.
8	4	—	—	—
14	1	6	—	—
16	1	7	—	—
18	2	7	—	—
24	3	9	—	—
28	4	10	—	—
30	4	11	—	—
50	2	8	15	—
54	3	9	15	—
60	4	10	16	—
76	1	6	12	19
100	3	9	16	22

Electrostatic Capacity.—The mean electrostatic capacity from wire to wire of the pairs in any length of cable should not exceed the following figures :—

For small distribution cables (up to 15 pairs)	0·095	microfarads per mile.
For main and composite cables—		
6½ and 10 lbs. conductors . .	0·075	" "
20 lbs. and heavier " . .	0·065	" "
For multiple twin cables, all conductors	0·065	" "

The temperature of the cables during the tests should not be lower than 50° F.

Insulation Resistance.—The insulation tests should be made with a battery of not less than 300 volts, and if required 600 volts may be used. The insulation resistance of each wire in the cable from every other wire in the cable, and from the lead sheathing, should be not less than 5000 megohms for a statute mile after one minute's electrification at a temperature of not less than 50° F. The galvano-

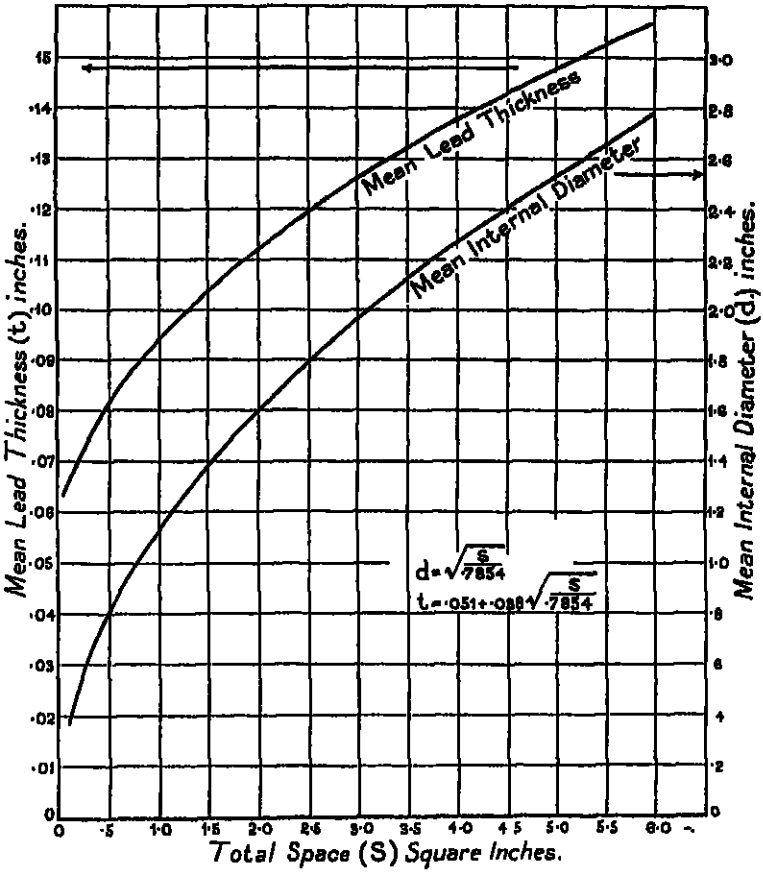


FIG. 41.

meter readings during the test to indicate perfectly steady electrification. The cable should be tested dry and the ends metal capped and sealed immediately after the tests are completed. The foregoing insulation figure of 5000 megohms applies to all conductors in all cables, except in multiple twin cables where a minimum of 25,000 megohms for a statute mile is specified. Although not scientifically correct, it is usual to speak of insulation resistance in megohms

"*per*" mile. No harm is likely to arise so long as it is clear that in this case "per" does not mean divide.

Shop Inspection.—In view of the high initial cost of large paper core cables, and the high cost of repairing any defect that may develop after laying the cables underground, it is desirable to take every precaution to prevent the introduction of the slightest defect in the course of manufacture, and for this reason the Post Office Specifications stipulate that the Inspecting Officer shall have free access to the contractors' works for the purpose of inspecting the process of manufacture in all its stages.

Electrical Testing.—Great care is necessary to prevent moisture from getting into the cable, and the ends are consequently not exposed to the air longer than is absolutely necessary to carry out the tests. Immediately the ends are opened they are plunged into melted paraffin wax, so as effectively to seal the cable from ingress of moisture. Groups of wires are tested simultaneously, first for conductor resistance and afterwards for capacity and insulation. The grouping is so arranged that each wire under test is surrounded by earthed wires during the insulation test, so that the insulation test also takes care of contacts between neighbouring wires. Further, each 2-pair core is tested for insulation against the cores adjacent to it, the 2-pair cores being grouped on the same principle as the single wires, and thus contacts between wires in neighbouring cores are found. It is usually convenient to express the length under test in decimals of a mile, and for conductor resistance all the conductors of the same gauge can be tested in series.

For example, take the case of two lengths of cable, each 179 yards long, tested in series, and containing 100 40 lb. conductors, and let the observed resistance at 62° F. be 444·5 ohms. This has to be reduced to 60° F., and the factor is

$$\frac{1}{1 + \cdot 0022221 \times 2} = 0{\cdot}995$$

$$179 \times 2 = 358 \text{ yards} = \cdot 203 \text{ mile.}$$

$$\text{Resistance per mile at } 60^\circ \text{ F.} = \frac{444{\cdot}5 \times \cdot 995}{100 \times \cdot 203} = 21{\cdot}78 \text{ ohms.}$$

The galvanometer generally used for the capacity and insulation tests is of the reflecting moving coil type. The capacity is determined by comparing the discharge from the cable with that obtained from a standard mica condenser, a battery of about 10 volts being used. In taking the wire to wire capacity, only one pair is tested at a time, the other wires in the cable, and the testing battery and apparatus, being insulated from earth. In large cables only 5 per cent. of the pairs are tested for wire to wire capacity, generally one or two pairs from each layer. In cables having less than 300 pairs, 10 per cent. of the pairs are tested for capacity. The following deflections were obtained from the cable previously referred to :—

257
265
261
250
290
273
265
267
260
277

266·5 mean.

The deflection obtained from a standard 0·01 microfarad condenser was 215 divisions, so that 1 microfarad would theoretically give 21,500 divisions. Then, taking the mean of the deflections, we have

21,500 divisions : 266·5 divisions : : 1 microfarad : actual capacity ;

$$\text{or } \frac{266 \cdot 5}{21500} = \text{actual capacity in m.f.}$$

But the results should be stated in capacity per mile. Hence

·203 mile : 1 mile : : actual capacity : capacity per mile.

$$\therefore \text{Capacity per mile} = \frac{\text{actual capacity}}{\cdot 203}$$

$$= \frac{266 \cdot 5}{21{,}500 \times \cdot 203} = 0 \cdot 0610 \text{ m.f.}$$

If the number of divisions equivalent to 1 microfarad be denoted by K, the length in decimals of a mile by l, and the deflection by d, the wire to wire capacity per mile $= \frac{d}{K \times l}$.

The capacities per mile corresponding to the maximum and minimum deflections are also calculated, and in this case were for

250 divisions, ·0664 m.f. per mile.
290 „ ·0573 „ „

The leads from the galvanometer to the cable should not be of the concentric rubber dielectric type, otherwise the apparent wire to wire capacity of the cable will be low. Separate leads should be used, and if they are appreciably long the capacity of the leads must be allowed for in the calculations.

Insulation Resistance.—To save time in testing cables containing a large number of wires, it is desirable to group as many as practicable together in one test, provided that no two wires which may be in contact are put into the same group test. It is convenient, therefore, to proceed on the following lines :—

(*a*) Take one wire of a pair and join the other to earth.

(*b*) In the same layer, only alternate *pairs* should be tested in the same group.

(*c*) Only alternate *layers* should be tested in the same group.

For example, the 50-pair cable previously referred to was made up as follows, the figures in the circles denoting the number of pairs in the centre and layers. From the centre three pairs, one wire is taken and the remaining five joined together and earthed. All the 9 pairs in the first layer are earthed; eight wires are taken from alternate pairs in the next layer, containing 16 pairs, and the remaining wires joined to earth, and all the 22 pairs are joined to earth together with the lead sheath. So that the first test consists of nine wires tested against all the other wires and the sheathing earthed.

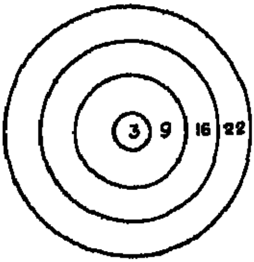


FIG. 42.

These wires after test are joined to earth, and the companion wire of the pair is tested, giving nine wires grouped together, as in the first test, against all the other wires and the sheathing.

The alternate pairs are then dealt with in the same way, so that there are four tests of nine wires.

Taking next the layer containing 9 pairs and the layer containing 22 pairs, a wire is selected from each of four alternate pairs in the 9-pair layer, and a wire from each of eleven alternate pairs in the 22-pair layer, so that there are fifteen wires grouped together and tested against all the other wires in the cable and the sheathing earthed. This, again, admits of four tests of fifteen wires. It will be seen that there are two wires in the centre and two wires in the 9-pair layer which have not yet been tested. These must be taken one wire at a time against all the others earthed, so that the complete insulation tests consist of:—

4 tests of	9 wires	= 36
4 tests of	15 wires	= 60
4 tests of	1 wire	= 4
		100

that is to say, twelve tests for insulation have to be taken to ensure that the cable is free from contacts and up to the required standard. In testing a cable of 1000 pairs (2000 wires), only ten insulation tests are necessary, as the wires group more conveniently than in the example chosen above.

A thin tinned copper wire is found to be the most convenient means of connecting the wires which have to be grouped together, and the necessary connections can be made quite rapidly by the assistant after a little practice.

The constant or figure of merit of the galvanometer is taken through a known resistance, usually 1 or 10 megohms. In the case above, the deflection obtained through 10 megohms, using $\frac{1}{3000}$ shunt, was 261 divisions, so that with the same battery a deflection of one division would be obtained through a resistance of 783,000 megohms. Multiplying this number by the length in miles of the cable the testing constant is obtained:

$$783{,}000 \times 0{\cdot}203 = 159{,}000.$$

A stop watch is used for timing the application of the testing battery, and exactly at the end of 60 seconds the deflection is noted. In the case of the 9-wire groups, the deflection was fifty-six divisions on the unshunted galvanometer. For one wire the deflection would, of course, have been only one-ninth of this. Consequently, to obtain the insulation resistance of one mile of single wire, the testing constant 159,000 is divided by $\frac{56}{9}$. Hence

$$\text{Insulation resistance of 1 mile of single wire} = \frac{159000 \times 9}{56}$$
$$= 25{,}600 \text{ megohms.}$$

The deflection obtained from the fifteen wire groups was ninety divisions, so that

$$\text{Insulation resistance of a mile of single wire} = \frac{159000 \times 15}{90}$$
$$= 26{,}500 \text{ megohms.}$$

The deflection obtained from the single wires was six divisions, giving for a mile of single wire

$$\frac{159000}{6} = 26{,}500 \text{ megohms.}$$

If K be the figure of merit of the galvanometer in megohms, l the length in miles of the cable under test, n the number of wires grouped together, and d the deflection in divisions given by the group, then

$$\text{Insulation resistance in megohms of a mile of single wire} = \frac{K \times l \times n}{d}$$

Prior to commencing the electrical tests the cable should be examined for crossed pairs, by passing in turn a current along each wire with a bell in circuit, and checking that each wire is in its proper sequence at both ends of the cable. The cable should be closed up and sealed as quickly as possible after the insulation tests.

No. 174—1923.

BRITISH STANDARD SPECIFICATION FOR HARD DRAWN COPPER WIRE FOR TELEGRAPH AND TELEPHONE PURPOSES

Definitions

Definition of Piece

1. The term "piece" shall denote a single length of wire without joint of splice of any description either before being drawn or in the finished wire.

Definition of Coil.

2. The term "coil" shall denote one piece of wire in the form of a coil.

Definition of Bundle

3. The term "bundle" shall denote two or more coils properly bound together.

Definition of Parcel

4. The term "parcel" shall denote any quantity of finished wire presented for examination and test at any one time.

Definition of Test Sample.

5. The term "test sample" shall denote a sample taken for test in accordance with the Specification.

Manufacture

Material

6. The wire shall be of high conductivity copper.

Dimensions

7. The wire shall be drawn in continuous pieces of the respective weights and diameters given in the Table.

Every piece may be tested for diameter in any part without cutting.

Freedom from Defects

8. The wire shall be approximately circular in section, smooth, uniform in quality, pliable, free from scale, inequalities, spills, splits, and other defects. Every coil may be examined for defects.

Tests

General

9. The wire will be inspected and tested at the Contractor's works. The Contractor shall supply, without making any claim or charge for same, all the necessary machinery, apparatus, convenience, labour, and assistance required for the purpose. The testing plant shall be under the immediate control of the Purchaser or his representative during the tests. All the wire wasted in tests shall be supplied by the Contractor free of charge.

Test Samples

10. (*a*) Samples may be cut from the ends of every piece for the mechanical tests (see Clause 11).

(*b*) Not more than five per cent. of the test samples of any one size of wire will be cut from any part other than the ends for the mechanical tests. Pieces thus cut shall not be welded or otherwise jointed together, but each length shall be bound up into a separate coil. These pieces will be accepted and paid for if the wire satisfies all the requirements of this Specification.

(*c*) Any piece may be tested for electrical resistance. The length to be tested, if desired by the Purchaser or his representative, shall be not less than $\frac{1}{10}$ English statute mile. The piece will not ordinarily be cut for this test, but similar test samples may be cut from not more than 2 per cent. of the pieces when it is desired to use the formula in Clause 12. Test samples cut for this purpose will not be paid for.

Mechanical Tests

11. (*a*) *Lapping Test.*—The test sample shall bear being closely lapped six times round wire of its own diameter, unlapped and again closely lapped six times round wire of its own diameter in the same direction as the first lapping without breaking.

(*b*) *Twisting Test.*—The test sample shall withstand the following test without breaking:—

It will be gripped in two vices, one of which will be made to revolve at a speed not exceeding one revolution per second for the minimum number of twists in the length as specified in the Table. The twists shall be indicated by means of an ink mark which will form a spiral on the wire during torsion, and the full number of twists shall be visible between the vices.

(*c*) *Tensile Test.*—The breaking load of the wire when tested as follows and corrected to standard weight shall be not less than the value given in the Table:—

A lever testing machine shall be used of which the accuracy can be easily checked, and the machine adjusted if necessary. The test sample as cut from the piece will be placed in the machine without being straightened, or prepared in any way, before testing. Nine-tenths of the minimum breaking load shall be applied quickly, and the load shall then be increased steadily until the sample breaks. The time occupied in applying the remainder of the load shall be as nearly as possible 5 seconds, and the total time from the application of the load to the break shall be approximately 10 seconds.

Electrical Test

12. *Resistance Test.*—The electrical resistance per mile of the test sample multiplied by $\frac{W}{K}$ (C) shall not exceed that given in the Table.

K = standard weight per statute mile.
W = weight per mile of test sample, and
C = multiplier constant for correcting to 60° F.

The multiplier constant shall be in accordance with British Standard Specification No. 7.

The test shall be carried out with approved apparatus, supplied by

the Contractor. Certificates as to the accuracy of the apparatus shall be provided, and the Purchaser shall have the right to satisfy himself that the apparatus is correct.

Rejection

13. Any piece from which the test samples fail to pass any one of the requirements of this Specification may be rejected. Should five per cent. of the pieces in any parcel of wire fail to pass any of the requirements of this Specification, the whole of such parcel will be rejected. On no account shall any rejected parcel, or any part thereof, be again presented for examination and test.

Packing

Marking and Packing Accepted Material

14. Each piece shall be made into a coil and separately bound with four bindings, each of two lappings, of either stout string, or 100 lb. per mile annealed copper wire (or its equivalent), as may be ordered. In no case shall two or more pieces be linked or otherwise jointed together. The eye of the coil shall be not less than 19 inches and not more than 20 inches in diameter. The coil shall be wrapped with canvas.

Each piece shall be labelled with a metal or other approved label, marked with the maker's name, and with the weight of the coil to the nearest pound.

TABLE

Hard Drawn Copper Wire

1	2	3	4	5	6	7	8	9	10	11
Weight per Statute Mile.			Diameter.			Minimum Breaking Load of Wire of Standard Weight.	Minimum Number of Twists.	Maximum Resistance per Mile of Standard Weight at 60° F.	Weight of each Piece (or Coil).	
Standard.	Minimum.	Maximum.	Standard.	Minimum.	Maximum.				Minimum.	Maximum.
lbs.	lbs.	lbs.	in.	in.	in.	lbs.		Standard ohms.	lbs.	lbs.
800	784	816	0·2237	0·2215	0·2259	2400	15	1·0984		
600	588	612	0·1937	0·1918	0·1956	1800	20	1·4649		
400	392	408	0·1582	0·1566	0·1598	1250	25 In 6 ins.	2·2017	100	140
300	294	306	0·1370	0·1356	0·1384	945	30	2·9413		
200	196	204	0·1119	0·1108	0·1130	640	20	4·4206	75	140
150	147	153	0·0969	0·0959	0·0979	490	25 In 3 ins.	5·8999		
100	98	102	0·0791	0·0783	0·0799	330	30	8·8584	75	140
70	68·5	71·5	0·0662	0·0655	0·0669	230	35	12·655	50	140

No. 175—1923.

BRITISH STANDARD SPECIFICATION FOR BRONZE WIRE FOR TELEGRAPH AND TELEPHONE PURPOSES

Definitions

Definition of Piece

1. The term "piece" shall denote a single length of wire without joint or splice of any description, either before being drawn or in the finished wire.

Definition of Coil

2. The term "coil" shall denote one piece of wire in the form of a coil.

Definition of Bundle

3. The term "bundle" shall denote two or more coils properly bound together.

Definition of Parcel

4. The term "parcel" shall denote any quantity of finished wire presented for examination and test at any one time.

Definition of Test Sample

5. The term "test sample" shall denote a sample taken for test in accordance with the Specification.

Manufacture

Material

6. The wire shall be a copper alloy having properties which will meet the specified tests.

Dimensions

7. The wire shall be drawn in continuous pieces of the respective weights and diameters given in the Table.

Every piece may be tested for diameter in any part without cutting.

Freedom from Defects

8. The wire shall be approximately circular in section, smooth, uniform in quality, pliable, free from scale, inequalities, spills, splits, and other defects. Every coil may be examined for defects.

Tests

General

9. The wire will be inspected and tested at the Contractor's Works. The Contractor shall supply, without making any claim or charge for same, all necessary machinery, apparatus, convenience, labour, and assistance required for the purpose. The testing plant shall be under

the immediate control of the Purchaser or his representative during the tests. All the wire wasted in tests shall be supplied by the Contractor free of charge.

Test Samples

10. (*a*) Samples may be cut from the ends of every piece for the mechanical tests (see Clause 11).

(*b*) Not more than five per cent. of the test samples of any one size of wire will be cut from any part other than the ends for the mechanical tests. Pieces thus cut shall not be welded or otherwise jointed together, but each length shall be bound up into a separate coil. These pieces will be accepted and paid for if the wire satisfies all the requirements of this Specification.

(*c*) Any piece may be tested for electrical resistance. The length to be tested, if desired by the Purchaser or his representative, shall be not less than $\frac{1}{80}$ English statute mile. The piece will not ordinarily be cut for this test, but similar test samples may be cut from not more than 2 per cent. of the pieces when it is desired to use the formula in Clause 12. Test samples cut for this purpose will not be paid for.

Mechanical Tests

11. (*a*) *Lapping Test.*—The test sample shall bear being closely lapped six times round wire of its own diameter, unlapped and again closely lapped six times round wire of its own diameter in the same direction as the first lapping without breaking.

(*b*) *Twisting Test.*—The test sample shall withstand the following test without breaking:—

It will be gripped in two vices, one of which will be made to revolve at a speed not exceeding one revolution per second for the minimum number of twists in the length as specified in the Table. The twists shall be indicated by means of an ink mark which will form a spiral on the wire during torsion, and the full number of twists shall be visible between the vices.

(*c*) *Tensile Test.*—The breaking load of the wire when tested as follows and corrected to Standard weight shall be not less than the value given in the Table:—

A lever testing machine shall be used of which the accuracy can be easily checked, and the machine adjusted if necessary. The test sample as cut from the piece will be placed in the machine without being straightened or prepared in any way before testing. Nine-tenths of the minimum breaking load shall be applied quickly, and the load shall then be increased steadily until the sample breaks. The time occupied in applying the remainder of the load shall be, as nearly as possible, 5 seconds, and the total time from the application of the load to the break shall be approximately 10 seconds.

Electrical Tests

12. *Resistance Test.*—The electrical resistance per mile of the test sample multiplied by $\frac{W}{K}$ (C) shall not exceed that given in the Table.

K = standard weight per statute mile.
W = weight per mile of test sample, and
C = multiplier constant for correcting to 60° F. (see Appendix).

The test shall be carried out with approved apparatus supplied by the Contractor. Certificates as to the accuracy of the apparatus shall be provided, and the Purchaser shall have the right to satisfy himself that the apparatus is correct.

Rejection

13. Any piece from which the test samples fail to pass any one of the requirements of this Specification may be rejected. Should five per cent. of the pieces in any parcel of wire fail to pass any of the requirements of this Specification, the whole of such parcel will be rejected. On no account shall any rejected parcel, or any part thereof, be again presented for examination and test.

PACKING

Marking and Packing Accepted Material

14. Each piece shall be made into a coil and separately bound with four bindings, each of two lappings, of either stout string or 100 lb. per mile annealed copper wire (or its equivalent), as may be ordered. In no case shall two or more pieces be linked or otherwise jointed together. The eye of the coil shall be in accordance with the limits specified in the Table. The coil shall be wrapped with canvas.

Each piece shall be labelled with a metal or other approved label, marked with the maker's name, and with the weight of the coil to the nearest pound.

TABLE

BRONZE WIRE

1	2	3	4	5	6	7	8	9	10	11	12	13
Weight per Statute Mile.			Diameter.			Minimum Breaking Load of Wire of Standard Weight.	Minimum Number of Twists.	Maximum Resistance per Mile of Standard Weight at 60° F.	Weight of Each Piece (or Coil).		Diameter of Eye of Coil.	
Standard.	Minimum.	Maximum.	Standard.	Minimum.	Maximum.				Minimum.	Maximum.	Minimum.	Maximum.
lbs.	lbs.	lbs.	in.	in.	in.	lbs.		ohms.	lbs.	lbs.	in.	in.
300	294	306	0·137	0·135	0·139	1,320	12 in 6 ins.	6·07	100	140	19	20
150	147	153	0·097	0·095	0·098	700	8 in 3 ins.	12·14	75	140	19	20
100	98	102	0·079	0·078	0·080	485	12	18·2	60	140	19	20
70	68·5	71·5	0·066	0·065	0·067	345	15	26·0	50	140	19	20
40	39	41	0·050	0·0495	0·0505	200	20	45·5	20	30	9	10

APPENDIX

Multiplier Constant for Bronze Wire

Temperature in Degrees F. at which Resistance is Measured.	Multiplier Constant for Converting to 60° F.	Temperature in Degrees F. at which Resistance is Measured.	Multiplier Constant for Converting to 60° F.
32	1·0293	59	1·0010
33	1·0282	60	1·0000
34	1·0271	—	—
35	1·0261	61	0·9990
36	1·0250	62	0·9980
37	1·0239	63	0·9970
38	1·0229	64	0·9960
39	1·0218	65	0·9949
40	1·0207	66	0·9939
41	1·0197	67	0·9929
42	1·0186	68	0·9919
43	1·0176	69	0·9909
44	1·0165	70	0·9899
45	1·0155	71	0·9889
46	1·0144	72	0·9880
47	1·0134	73	0·9870
48	1·0123	74	0·9860
49	1·0113	75	0·9850
50	1·0103	76	0·9840
51	1·0092	77	0·9830
52	1·0082	78	0·9820
53	1·0072	79	0·9811
54	1·0061	80	0·9901
55	1·0051	81	0·9791
56	1·0041	82	0·9781
57	1·0031	83	0·9772
58	1·0020	84	0·9762
—	—	85	0·9752

No. 176—1923.

BRITISH STANDARD SPECIFICATION FOR COPPER BINDING AND JOINTING WIRE FOR TELEGRAPH AND TELEPHONE PURPOSES

Definitions

Definition of Piece

1. The term "piece" shall denote a single length of wire without joint or splice of any description, either before being drawn or in the finished wire.

Definition of Coil

2. The term "coil" shall denote one piece of wire in the form of a coil.

Definition of Bundle

3. The term "bundle" shall denote two or more coils properly bound together.

Definition of Parcel

4. The term "parcel" shall denote any quantity of finished wire presented for examination and test at any one time.

Definition of Test Sample

5. The term "test sample" shall denote a sample taken for test in accordance with the Specification.

MANUFACTURE

Material

6. The wire shall be pure soft electrolytic copper, plain or tinned, as shown in the Table.

Dimensions

7. The wire shall be drawn in continuous pieces of the respective weights and diameters given in the Table.

Every piece may be tested for diameter in any part without cutting.

Freedom from Defects

8. The wire shall be approximately circular in section, uniformly annealed soft, pliable, free from scale, inequalities, spills, splits, and other defects. Every coil may be examined for defects.

Tinning

9. (Items 3, 4, and 5 of Table.) The surface of the wire shall be tinned uniformly and shall be thoroughly clean. The wire shall be visually examined for tinning and tested for elongation as specified in Clause 11 (*d*).

TESTS

Test Samples

10. Samples may be cut from the ends of every piece for the mechanical tests (see Clause 11).

Mechanical Tests

11. (*a*) *Lapping Test.*—The test sample shall bear being closely lapped six times round wire of its own diameter, unlapped and again closely lapped six times round wire of its own diameter in the same direction as the first lapping, again unlapped and finally lapped a third time as before without breaking, that is to say, on off, on off, on.

(*b*) *Twisting Test.*—The test sample shall withstand the following test without breaking:—

It will be gripped in two vices, one of which will be made to revolve at a speed not exceeding one revolution per second for the minimum number of twists in the length as specified in the Table. The twists shall be indicated by means of an ink mark which will form a spiral on the wire during torsion, and the full number of twists shall be visible between the vices.

(*c*) *Tensile Test.*—The breaking load of the wire when tested as follows shall be within the limits given in the Table:—

A lever testing machine shall be used of which the accuracy can be easily checked and the machine adjusted if necessary. The test sample as cut from the piece shall be placed in the machine without being straightened or prepared in any way before testing. Nine-tenths of the minimum breaking load shall be applied quickly and the load shall then be increased steadily until the sample breaks. The time occupied in applying the remainder of the load shall be as nearly as possible 20 seconds, and the total time from the application of the load to the break shall be approximately 30 seconds.

(*d*) *Elongation Test.*—A test sample 10 inches long shall be gripped in an elongation machine, and steadily elongated until it breaks. The duration of the test shall be approximately 30 seconds. The elongation shall be measured after fracture and shall comply with the figures given in the Table.

Rejection

12. Any piece from which the test samples fail to pass any one of the requirements of this Specification may be rejected. Should 10 per cent. of the pieces in any parcel of wire fail to pass any of the requirements of this Specification, the whole of such parcel will be rejected. On no account shall any rejected parcel, on any part thereof, be again presented for examination and test.

PACKING

Marking and Packing Accepted Material

13. Items 1 and 2 of the Table shall be smoothly and uniformly coiled so that the eye of the coil shall not be less than 9 inches nor more than 10 inches in diameter, and each coil shall be separately bound. In no case shall two or more pieces be linked or otherwise joined together. The coils shall be made up in bundles properly bound and within the limits of weight shown in the Table.

Each bundle to be weighed separately and labelled with a metal or other approved label, marked with the maker's name, designation of wire, weight of bundle to the nearest pound, and year of supply. The label shall be firmly affixed to the inner part of the coil or bundle.

Each bundle shall be wrapped in canvas and be packed and delivered as ordered.

Items 4 and 5 of the Table shall be supplied on suitable hard wood reels (which will become the property of the Purchaser). The weight of the reel empty and full shall be clearly and legibly stamped on each. The quantity supplied in each reel shall be as stated in the Table. Each reel shall be clearly and legibly stamped with the maker's name, designation of wire, and year of supply.

TABLE

COPPER BINDING AND JOINTING WIRE

1	2	3	4	5	6	7	8	9		10	11	12	13	14	15	16	17	18
Item No.	Designation.	Weight per Mile.			Diameter.			Tests for Strength and Ductility.				Weight of each Coil.		Weight of each Bundle.			Weight per Reel.	Remarks.
		Standard.	Minimum.	Maximum.	Standard.	Minimum.	Maximum.	Breaking Load.		No. of Twists in 3 inches (Min.).	Elongation per Cent.	Minimum.	Maximum.	Required Standard.	Minimum.	Maximum.		
								Minimum.	Maximum.									
		lbs.	lbs.	lbs.	in.	in.	in.	lbs.	lbs.			lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1	AA 3	40	39·2	40·8	0·050	0·0495	0·0505	68	84	44	25	3	10	14	13	15	—	Binding (Plain)
2	AA 5	50	49	51	0·0559	0·0554	0·0565	85	106	40	25	3	10	14	13	15	—	Binding (Plain)
3	AA 17	50	49	51	0·0559	0·0554	0·0565	—	—	—	25	3	10	14	13	15	—	Jointing (Tinned)
4	AA 11	—	—	—	0·0124	0·012	0·013	—	—	—	15	—	—	—	—	—	½	Jointing (Tinned)
5	AA 13	—	—	—	0·018	0·0175	0·0185	—	—	—	15	—	—	—	—	—	½	Jointing (Tinned)

No. 177—1923.

BRITISH STANDARD SPECIFICATION FOR COPPER TAPES AND BINDERS FOR TELEGRAPH AND TELEPHONE PURPOSES

Material

1. The tapes and binders shall be made of pure soft electrolytic copper wire of good quality.

Dimensions

2. The tapes and binders shall be of the dimensions given in the Tables. The binders shall be flattened uniformly at each end.

Manufacture

3. After rolling, both tapes and binders shall be re-annealed soft and shall be free from scale. The ends of both tapes and binders shall be smooth and free from burrs.

Elongation Test

4. The elongation test will be made by gripping a sample in an elongation machine, and steadily elongating the sample until it breaks. The duration of the test shall be approximately 30 seconds. The elongation shall be measured after fracture, and shall comply with the figures given in the Tables.

Packing

5. The tapes and binders shall be supplied in separate bundles of 100 each.

TABLE I

TAPES

1	2	3	4	5	6	7
Designation.	Approximate Weight per Mile of Wire used for Manufacture.	Length.	Width.	Thickness.	Minimum Elongation per Cent. on 5 ins.	Approximate Number to the Pound (lb.).
	lbs.	ins.	in.	in.		
Tapes, Copper No. 1 .	50	$8\frac{1}{2}$	$\frac{5}{32}$	0·014	20	170
Tapes, Copper No. 2 .	100	9	$\frac{5}{16}$	0·024	25	77
Tapes, Copper No. 3 .	150	9	$\frac{1}{4}$	0·026	25	53

TABLE III

Binders

1	2	3	4	5	6	7	8
Designation.	Length.	Length of Middle Portion.	Diameter of Middle Portion (Variation not to Exceed 0·002 inch).	Width of Flats.	Thickness of Flats.	Minimum Elongation per Cent. on the Middle 10 ins.	Approximate Number to the Pound (lb.).
	ins.	ins.	in.	in.	in.		
Binders, Copper No. 1 .	17	6¼	0·079	3/32	0·036	15	37
Binders, Copper No. 2 .	17	6⅛	0·097	⅛	0·048	15	25
Binders, Copper No. 3 .	20½	7	0·112	3/16	0·056	20	17
Binders, Copper No. 4 .	23	7½	0·158	¼	0·072	20	8

No. 178—1923.

BRITISH STANDARD SPECIFICATION FOR BRONZE TAPES AND BINDERS FOR TELEGRAPH AND TELEPHONE PURPOSES

Material

1. The tapes and binders shall be made of annealed bronze wire of which the composition shall be 99·0 to 99·5 per cent. of copper and 0·4 to 0·9 per cent. of tin. The total percentage of impurities shall be not greater than 0·2 per cent.

Dimensions

2. The tapes and binders shall be of the dimensions given in the Tables. The binders shall be flattened uniformly at each end.

Manufacture

3. After rolling, both tapes and binders shall be re-annealed soft and shall be free from scale. The ends of both tapes and binders shall be smooth and free from burrs.

Elongation Test

4. The elongation test will be made by gripping a sample in an elongation machine and steadily elongating the sample until it breaks. The duration of the test shall be approximately thirty seconds. The elongation shall be measured after fracture, and shall comply with the figures given in the Tables.

Packing

5. The tapes and binders shall be supplied in separate bundles of 100 each.

TABLE I

TAPES

1	2	3	4	5	6	7
Designation.	Weight per Mile of Wire used for Manufacture.	Length.	Width.	Thickness.	Minimum Elongation per Cent. on 5 ins.	Approximate Number to the Pound (lb.).
	lbs.	ins.	in.	in.		
Tapes—Bronze No. 1	40	$6\frac{1}{2}$	$\frac{3}{32}$	0·020	20	260
Tapes—Bronze No. 2	40	9	$\frac{1}{8}$	0·014	15	200

TABLE II

BINDERS

1	2	3	4	5	6	7	8
Designation.	Length.	Length of Middle Portion.	Diameter of Middle Portion (Variation not to Exceed 0·002 in.).	Width of Flats.	Thickness of Flats.	Minimum Elongation per Cent. on the Middle 10 ins.	Approximate Number to the Pound (lb.).
	ins.	ins.	in.	in.	in.		
Binders—Bronze No. 1	12	6	0·066	$\frac{3}{64}$	0·035	15	80
Binders—Bronze No. 2	16	$6\frac{1}{4}$	0·097	$\frac{3}{16}$	0·035	15	28

No. 179—1923.

BRITISH STANDARD SPECIFICATION FOR COPPER JOINTING SLEEVES No. 10 FOR TELEGRAPH AND TELEPHONE PURPOSES

Material

1. The sleeves shall be made of pure soft electrolytic copper.

Dimensions

2. The sleeves shall take two wires, one maximum diameter 0·051 inch, minimum diameter 0·049 inch; the other, maximum diameter 0·0285 inch, minimum diameter 0·0275 inch. The sleeves shall conform to the particulars given in the Table.

Manufacture

3. The sleeves shall be solid drawn, annealed, clean and bright inside, and the ends shall be free from burrs.

Samples

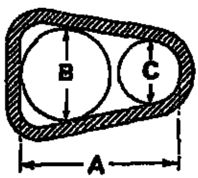
4. The Contractor, if required, shall submit not less than ten sleeves for approval before the bulk of the order is proceeded with.

Packing

5. The sleeves shall be supplied neatly packed in boxes, each containing 500 sleeves. Each box shall be labelled to show the quantity and description of the contents.

TABLE

COPPER JOINTING SLEEVES NO. 10



1	2	3	4						5
Designation.	Length of Sleeve.	Thickness of Metal.	Internal Dimensions of Tube.						Minimum Weight per 100 Sleeves.
			A.		B.		C.		
			Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	
	in.	in.	in.	in.	in.	in.	in.	in.	ozs.
Sleeves, copper No. 10 for 40 lbs. and 12½ lbs. wires .	[illegible]	0·02	0·085	0·087	0·052	0·054	0·030	0·032	1·84

No. 180—1923.

BRITISH STANDARD SPECIFICATION FOR COPPER JOINTING SLEEVES Nos. 1, 2, 3, 4, AND 7 FOR TELEGRAPH AND TELEPHONE PURPOSES

Material

1. The sleeves shall be made of pure soft electrolytic copper.

Dimensions

2. The sleeves shall conform to the particulars given in the Table.

Manufacture

3. The sleeves shall be solid drawn, annealed, clean and bright inside, and the ends shall be free from burrs.

Twisting Test

4. Two copper wires of the maximum size shown in Column 2 of the Table will be inserted through the whole length of the sleeve. The sleeve and wire will then be fixed in two close-fitting jointing clamps ¾ inch wide, the outer edges of which shall be flush with the ends of the sleeve. These clamps will be revolved in opposite directions, and the sleeves shall withstand without cracking or breaking, the specified number of twists shown in Column 7 of the Table.

Samples

5. The Contractor, if required, shall submit not less than ten sleeves of each size for approval before the bulk of the order is proceeded with.

Packing

6. The sleeves shall be supplied neatly packed in boxes each containing 500 sleeves. Each box shall be labelled to show the quantity and description of the contents.

TABLE

COPPER JOINTING SLEEVES, NOS. 1, 2 3, 4, AND 7.

1	2		3	4	5	6	7
Designation.	Diameter of Wire for which Sleeve is Required.		Length of Sleeve.	Thickness of Metal.	Minimum Internal Dimensions, Major and Minor Axis.	Minimum Weight per 100 Sleeves.	Number of Twists.
	Maximum.	Minimum.					
	in.	in.	ins.	in.	in.	ozs.	
Sleeves copper,							
No. 1 (long) } for 150	0·098	0·096	4½	0·022	0·204 × 0·101	27½	6
No. 2 (short) } lb. wire	0·098	0·096	2	0·022	0·204 × 0·101	12	2½
Sleeves copper,							
No. 3 (long) } for 100	0·080	0·078	3	0·022	0·166 × 0·082	15¼	5
No. 4 (short) } lb. wire	0·080	0·078	1½	0·022	0·166 × 0·082		2½
Sleeves copper,						9	
No. 7, for 20 lb. wire	0·036	0·035	1½	0·022	0·076 × 0·038	4¼	2½

No. 181—1923.

BRITISH STANDARD SPECIFICATION FOR BRONZE JOINTING SLEEVES Nos. 5, 6, 8, 9, 11 AND 12, FOR TELEGRAPH AND TELEPHONE PURPOSES

Material

1. The sleeves shall be made of annealed bronze of which the composition shall be 99·0 to 99·5 per cent. of copper and 0·4 to 0·9 per cent. of tin. The total percentage of impurities present shall be not greater than 0·2.

Dimensions

2. The sleeves shall conform to the particulars given in the Table.

Manufacture

3. The sleeves shall be solid drawn, annealed, clean and bright inside, and the ends shall be free from burrs.

Twisting Test

4. Two bronze wires of the maximum size shown in Column 2 of the Table will be inserted through the whole length of the sleeve. The sleeve and wire will then be fixed in two close-fitting jointing clamps ¾ inch wide, the outer edges of which shall be flush with the ends of the sleeve. These clamps will be revolved in opposite directions, and the sleeve shall withstand without cracking or breaking the specified number of twists shown in Column 7 of the Table.

Samples

5. The Contractor, if required, shall submit not less than ten sleeves of each size for approval before the bulk of the order is proceeded with.

Packing

6. The sleeves shall be supplied neatly packed in boxes, each containing 500 sleeves. Each box shall be labelled to show the quantity and description of the contents.

TABLE

BRONZE JOINTING SLEEVES, NOS. 5, 6, 8, 9, 11 AND 12

1	2		3	4	5	6	7
Designation.	Diameter of Wire for which Sleeve is Required.		Length of Sleeve.	Thickness of Metal.	Minimum Internal Dimensions, Major and Minor Axis.	Minimum Weight per 100 Sleeves.	Number of Twists.
	Maximum.	Minimum.					
	in.	in.	ins.	in.	in.	ozs.	
Sleeve bronze,							
No. 5 (long) for 40 lb. wire	0·051	0·049	2⅛	0·018	0·108 × 0·053	7¼	5
No. 6 (short) for 40 lb. wire	0·051	0·049	1⅝	0·018	0·108 × 0·053	4¾	2½
Sleeve bronze,							
No. 8 (long) for 70 lb. wire	0·067	0·065	2¾	0·018	0·140 × 0·069	9¾	5
No. 9 (short) for 70 lb. wire	0·067	0·065	1¾	0·018	0·140 × 0·069	¼	2½
Sleeve bronze,							
No. 11 (long) for 150 lb. wire	0·098	0·096	5	0·022	0·204 × 0·101	30½	6
No. 12 (short) for 150 lb. wire	0·098	0·096	2¼	0·022	0·204 × 0·101	13¾	2½

CHAPTER VI

INDIA-RUBBER, GUTTA-PERCHA, AND BALATA

Rubber is obtained from a milky fluid or latex which occurs in the veins of the bark of certain trees and shrubs found in tropical regions. The latex is coagulated either by heat or chemicals, and the curd is the raw rubber. The principal rubber-bearing tree is the *Hevea Brasiliensis*, which grows wild on the banks of the Amazon River, and from which the best rubber, known as Fine Hard Para, is obtained. This tree is now largely cultivated in Ceylon and the Federated Malay States, and the rubber obtained from these sources is generally known as Plantation rubber. The latex is tapped from the tree by cutting a narrow groove not quite through the bark —the latex is not the sap—and the fluid as it slowly drains out is caught in a cup near the bottom of the groove, where a small zinc channel piece is driven into the bark to guide the fluid into the cup. There are different methods of tapping in favour in different localities, and considerable importance is attached to the process, since it affects the yield. In coagulating the latex in the Para district of Brazil, the heating method is followed. A small wood fire is kindled and covered with a cone-shaped flue open to the air to concentrate the smoke to the desired part. A little of the latex is poured on a stout wood-rod somewhat like a broom handle, and is then held in the smoke. The heat drives off the moisture and the rubber adheres to the rod. This process is repeated until a lump several pounds in weight is obtained, when the rubber is cut off the stick and is ready for transport to Europe. This smoking process certainly produces excellent results, and its efficacy may be due to the fact that it prevents fermentation taking place in any part of the rubber. It is obvious that in tropical climates undesirable bacteria are likely to get into the latex after it is tapped, and the tar acids in the smoke, together with the heat, would no doubt sterilise the latex during the coagulation process. The characteristic odour of Para rubber is strongly suggestive of creosote, and is probably due to the presence of traces of tar acids obtained from the smoking process. Rubber obtained from other trees and under unskilled supervision sometimes possesses an odour which is very objectionable and not unlike rotten cheese, due to the fact that the rubber has probably been allowed to ferment after tapping. In Ceylon and the Straits Settlements coagulation is effected by means of organic

acids, such as ascetic acid, and the process is under the control of skilled chemists. It is not surprising, therefore, that plantation rubber is approximating more and more as time goes on to a product of uniform quality, and it is at present very largely used in rubber factories. There are several other kinds of trees from which rubber is obtained, such as *Castilloa elastica* (Central America), *Ficus elastica* (Burmah), *Ficus Vogelii* (Gold Coast), *Kicksia Africana* (Central Africa), etc. The collection and coagulation in some of these districts are not efficiently supervised, with the result that the products are far from uniform in quality, and frequently the rubber is allowed to ferment and develop the objectionable odours referred to above. In Porritt's "Chemistry of Rubber" * the reader will find an up-to-date discussion of the chemical constitution of rubber, and it must suffice here to say that the principal ingredient of the rubber as it reaches the home market is a hydrocarbon of the terpene series, $C_{10}H_{16}$, together with a natural resin and natural proteins. In fine Para rubber the percentage of resin on the washed rubber seldom exceeds 3½ per cent., whereas for some of the low grade rubbers it may reach 20 per cent. The following table is extracted from Porrit's "Chemistry of Rubber":—

Rubber.	Loss on Washing Calculated on Crude.	Ash.	Resin.	Proteins $= (N_2 \times 6.25)$.
		Calculated on Dry Washed Material.		
	per cent.	per cent.	per cent.	per cent.
Para, fine hard	17-19	—	—	—
Hard entrefine	18-20	—	—	—
Soft cure	20-22	0·25-0·5	2·5-3·5	2·5-3·0
Coarse entrefine	22-25	—	—	—
Weak fine	14-16	—	—	—
Plantation	1-2	0·25-0·5	1·5-3·0	2·5-3·0
Ceara scrap	28-32	1·0-1·75	4·5-5·5	5·0-6·0
Java	23-30	0·25-0·75	9·0-10·0	1·5-2·0
Amazon ball	20-24	—	4·5-5·5	—
Para negrohead	40-50	—	4·5-5·5	—
Assare scrap	35-50	—	4·5-6·0	—
Cameron ball	26-30	0·5-1·0	9·0-11·0	3·0-4·0
Benguela Niggers	30-40	1·0-2·0	5·0-6·0	—

It will be noticed that the Plantation figures for loss on washing are much lower than for any other grade, and since the washing process consists of passing the rubber through rolls to free it from dirt and impurities whilst a constant stream of water is fed on to the rubber, it will be evident that it will be cheaper to wash Plantation rubber than that obtained from other sources. The name caoutchouc is now applied to the pure hydrocarbon, which in high-grade rubber may be over 90 per cent. of the total weight of the

* "Chemical Monographs," published by Gurney & Jackson.

washed and dried raw rubber. An analysis by combustion of caoutchouc gave the following figures, as found by Gladstone and Hibbert:

Carbon	87·46 per cent.
Hydrogen . . .	12·00 „

This analysis agrees fairly well with the empirical formula C_5H_8, but so far the molecular weight of caoutchouc has not been determined. From its behaviour with sulphur, it is believed to be about 2500, and may be written $(C_{10}H_{16})n$. Harries suggested the following constitutional formula:

$$\begin{array}{l} CH_3 . \underset{\displaystyle \| }{C} . CH_2 . CH_2 . \underset{\displaystyle \|}{CH} \\ \quad\;\; CH . CH_2 . CH_2 . C . CH_3 \end{array}$$

But it has been criticised freely, and other constitutional formulæ somewhat similar have been suggested. There are many investigators working on the problem of producing caoutchouc synthetically, and perhaps some day the molecular weight and constitutional formula will be established beyond dispute.

The raw rubber, after being washed thoroughly and rolled into thin sheets, is hung up to dry in a dark, well-ventilated room at a temperature of about 80° F. for several weeks, and until all moisture has been removed. If the washed and dried raw rubber at this stage is heated to a temperature somewhat below that of boiling water, it becomes sticky and plastic. Although it was used in the raw condition for waterproofing fabrics in the early days of the rubber industry, the modern processes of vulcanisation are now almost universally adopted. What exactly happens chemically when rubber is vulcanised it is very difficult to say, but the processes adopted result in producing materials having properties quite unlike the raw material. There are two methods of vulcanising in general use, known respectively as "cold" cure and "steam" cure, the result of the processes being to cause a certain amount of sulphur to combine with the hydrocarbon of the raw rubber. The "cold" cure process is only applied to rubber in the form of small black tubing, thin sheet, or similar articles, and consists of dipping the rubber into a solution made up of forty parts of disulphide of carbon (CS_2) and one part of chloride of sulphur (S_2Cl_2). The rubber is removed after a few seconds from the solution and washed in a solution of ammonia in water to neutralise any free acid that may have been formed in the process, owing to decomposition of the sulphur chloride and formation of hydrochloric acid. A new process of cold-curing rubber has been patented recently (Patent No. 129,826, applied for 26th July, 1918, accepted 24th July, 1919) by Mr. S. J. Peachey, and is likely to prove of considerable industrial importance. A full description of the process is given in the "India Rubber Journal" for 19th June, 1920, and 23rd October, 1920. Briefly stated, the process consists of treating at air temperatures either pure rubber or rubber com-

pounded with various organic fillers, such as wood meal, waste leather, etc., with sulphur dioxide gas for about 10 minutes, then with a current of air, and finally with hydrogen sulphide gas for about 30 minutes. The reaction that takes p;ace between the gases is

$$2H_2S + SO_2 = 2H_2O + 3S.$$

The sulphur at the moment of liberation is in a very active form, and combines with the rubber, bringing about complete vulcanisation of thin articles, say, up to $\frac{1}{8}$ inch thick. Alternatively, the pure rubber can be dissolved in benzol, say, $2\frac{1}{2}$ per cent. of raw rubber in 100 grammes of benzol, and treated with sulphur dioxide until about 0·17 gramme of the latter has been taken up. A second quantity of 100 grammes of a similar rubber solution is treated with hydrogen sulphide until about 0·2 gramme of the latter has been taken up. The two solutions are then mixed, and after pectisation (setting to a jelly) has occurred the solvent is removed by evaporation. The method allows of organic dyes being employed, the colours being unaffected by the process. The writer has seen some of the products of the process, and very beautiful effects have certainly been obtained, but the subject is only of interest to the telephone industry as regards pure rubber tubing, rubber sheet, and other thin goods, and the reader is referred to the "India Rubber Journal" for further details. The small black tubing used for insulating bare wires on instrument boards is generally vulcanised by the cold cure process. All other kinds of rubber goods used by the Post Office are hot cured, which consists in incorporating mechanically about 4 to 5 per cent. of flowers of sulphur with the raw rubber, and afterwards subjecting the rubber to a temperature of about 280° F. for two or three hours in a press from which air is excluded. Mr. B. D. Porritt, in a paper on "The Action of Light and Oxygen on Rubber," read before a joint meeting of the Faraday Society and the Physical Society of London in October, 1920, and published by H.M. Stationery Office in a volume entitled "The Physics and Chemistry of Colloids," states that "technical experience has proved that with sulphur only the absence of air is necessary to ensure vulcanisation, while to secure satisfactory results by the 'dry heat' process the use of a positive catalyst such as litharge, in addition to sulphur, is indispensable." The temperature is obtained by means of steam, but this is not allowed to come into contact with the rubber. The time required for the process will depend upon the thickness of the article to be vulcanised and its composition, which may include filling materials such as zinc oxide, litharge (lead oxide), French chalk (magnesium silicate), and other earthy materials, which will be referred to later. A good general description of the details of the vulcanising process will be found in Terry's "India-rubber and its Manufacture." Vulcanised rubber generally contains sulphur in two forms :—

(1) Chemically combined with the rubber, or, at least, it cannot be dissolved out by the usual chemical processes.

(2) In a "free" or uncombined condition, and in a form which admits of its being dissolved out by means of acetone ($(CH_3)_2CO$) and other solvents.

Vulcanised rubber of the soft, easily stretched variety generally contains about 3½ per cent. of sulphur in the combined condition, the remainder being in the "free" state; whereas hard vulcanised rubber, which in this country is usually called ebonite, may contain as much as 32 per cent. of combined sulphur, the vulcanising process in the two cases being practically the same, except that a larger proportion of flowers of sulphur is incorporated on the mixing rolls with the raw rubber in the case of ebonite, and the temperature is kept up for a longer period. It was stated above that raw rubber when heated becomes tacky and plastic, but these properties disappear in vulcanised rubber which will admit of being heated for an hour in a dry heat of 270° F. without undergoing any appreciable change, and the best rubber will bear stretching to six or seven times its own length without showing any considerable permanent set. Joints in raw rubber can be made by pressing two edges together, and on vulcanisation the joint becomes strong and satisfactory. This method of joint-making cannot be applied after the rubber has been vulcanised, because the rubber has lost its tacky and plastic properties. The tensile strength of soft vulcanised rubber depends to a great extent on the degree of vulcanisation. This fact has been clearly brought out in a series of tests on plantation rubber, made by Mr. B. J. Eaton, F.I.C., F.C.S., Agricultural Chemist to the Federated Malay States, and published in Bulletin No. 27, "The Preparation and Vulcanisation of Plantation Para Rubber," price one dollar, obtainable from the London office of the Federated Malay States in Cannon Street, E.C. The volume contains 398 pages, dealing with various technical researches on plantation rubber, and the following figures and notes (see p. 113) are extracted from it. In all the tests given below, the rubber mixing consisted of nine parts of rubber to one part of sulphur, or 10 per cent. of sulphur calculated on the mixing. All vulcanisations were carried out at 140° C. in a steam-jacketed autoclave in moulds.

Ten per cent. of sulphur was used by Mr. Eaton for particular reasons. Such a high percentage for soft pure rubber goods is not allowed by the Post Office Specifications, which are referred to later. If the sulphur exceeds about 3½ per cent., the excess will almost certainly be present in the free or uncombined condition, and sulphur in this condition is found to make its way in time to the surface, leaving the rubber slightly porous and less resistant to oxidation by air, which is the principal cause of the perishing of vulcanised rubber. In the Post Office Specifications the tensile strength of rubber is not specified, but it is generally taken into account in judging the values of different samples of vulcanised rubber that may be submitted in connection with competitive tenders for Post Office supplies. When

Reference Number.	Time of Cure. Hours.	(a) Breaking Load. Kilogams per Square mm.	(b) Elongation at Break (orginal length = 100).	Product (a × b).
185 A ("Slab" rubber with a rapid rate of cure).	½	0·58	1174	680
	¾	0·86	1100	946
	1	1·08	1047	1130
	*1¼	1·42	1027	1458
	1½	1·45	973	1410
	1¾	0·53	735	389
	2	0·54	706	381
	2¼	0·24	528	126
185 B (sheet rubber with an intermediate rate of cure).	1½	0·86	1074	923
	1¾	0·96	1045	1003
	2	1·10	972	1069
	*2¼	1·40	986	1380
	2½	1·41	925	1304
	2¾	1·05	825	866
	3	0·38	612	232
	3¼	0·25	504	126
	3¾	0·17	380	64
	4¼	0·17	344	58
185 C (crepe rubber with a slow rate of cure).	1¾	0·54	1030	556
	2	0·79	1066	842
	2¼	0·88	1048	922
	2½	0·86	1022	878
	2¾	1·12	984	1102
	*3	1·28	973	1245
	3¼	1·30	930	1209
	3½	1·27	913	1159
	3¾	0·74	680	503
	4¼	0·29	531	153

The optimum rates of cure as determined by the maximum product are marked with an asterisk.

the vulcanised rubber is required for certain specific purposes it is found to be advantageous to incorporate with the rubber certain earthy materials, and the following grades are covered by the specification :—

A′ Quality (best grey).—Consisting of best rubber and sulphur only, the total sulphur not exceeding 4 per cent., of which not more than 1½ per cent. may be present in the free or uncombined condition.

B1 Quality (grey).—Consisting of best rubber, 50 per cent. zinc oxide, and 2½ per cent. sulphur.

C Quality (grey).—Consisting of best rubber, 70 per cent. zinc oxide, and 2½ per cent. sulphur.

D Quality (red).—Consisting of best rubber, antimony, and sulphur in the proportions sulphur 4½ per cent., and antimony 7 per cent. The antimony is present as antimony sulphide, and is the colouring agent.

E Quality (1).—Patching sheet for bicycle tyres. Consisting of

best rubber and sulphur only, the total sulphur not exceeding 3 per cent. The sheet is steam cured, and so treated after vulcanisation that the surface remains practically free from uncombined sulphur.

E Quality (2).—Tubing for bicycle valves. Consisting of best rubber (cut sheet) cold cured. Total sulphur not more than 1½ per cent. The surface of the finished tubing should be free from sulphur.

N.B.—E Quality is not required to pass the heat tests referred to later.

In the Post Office Specification it is stipulated that no remanufactured rubber and no rubber substitute may be used. The finished rubber must be homogeneous throughout and free from pores, air holes, and other defects. Rubber containing more than 3 per cent. of resin is not accepted as best quality, and the acetone extract (resin and free sulphur) from the vulcanised rubber must not exceed 5 per cent. of the total weight of rubber and sulphur. All qualities except E2 must stand the following heat tests without any appreciable deterioration in quality :—

A dry heat of 270° F. for one hour.
A moist heat of 320° F. for four hours.

Separate samples are taken for the heat tests.

The several qualities are used in the manufacture of the following articles :—

A Quality.—Gloves for high-tension work; rubber rings for Leclanché batteries; discs for penumatic carrier cages; telephone receiver bands; lift buffers; telegraph perforator bases; draught tubing; washers for telegraph punchers, etc.

B1 Quality.—Bulbs for acid syphons; syringes for battery work (the nozzles of the latter are of high-grade gutta-percha).

C Quality.—Square section washers for insulator spindles; mats; large washers (cable connection and cable distribution boxes).

D Quality.—Bands for telephone transmitter; bands for two-block agglomerate batteries; bands for six-block agglomerate batteries; feet for telegraph perforator bases; finger-stalls; washers for telephone receivers and tubing.

The dry heat test at a temperature of 270° F. is made in the Post Office laboratories in an oil-jacketed, polished aluminium oven, as illustrated in Fig. 43.

The oil used in the jacket is heavy cylinder (mineral) oil, which can be safely heated to 270° F. without giving off vapour. The temperature is well under control, and inside the oven it can readily be kept within one or two degrees. The rubber is placed on a grid made of glass tubes.

This heat test detects admixtures such as paraffin wax and other organic materials of low melting-point, the rubber after the test being quite changed in appearance and strength, if materials of this character have been incorporated with it.

The moist heat test at 320° F. is made in a Soxhlet autoclave tested to 15 atmospheres. It consists of a copper boiler fitted with

safety valve, pressure gauge, etc., and is made by Messrs. Baird & Tatlock, 14 Cross Street, Hatton Garden, E.C. 1. This test detects rubber containing an excess of free sulphur and rubber which has not been successfully vulcanised. Good, honest material will stand the test practically unchanged, but adulterated rubber sometimes goes on vulcanising with the free sulphur that is present, and becomes short and brittle, or if substitute be present in appreciable quantity the sample may collapse into a pulpy condition. These heat tests have been criticised very freely in various quarters, but it can safely be said that from the purchaser's point of view they supply

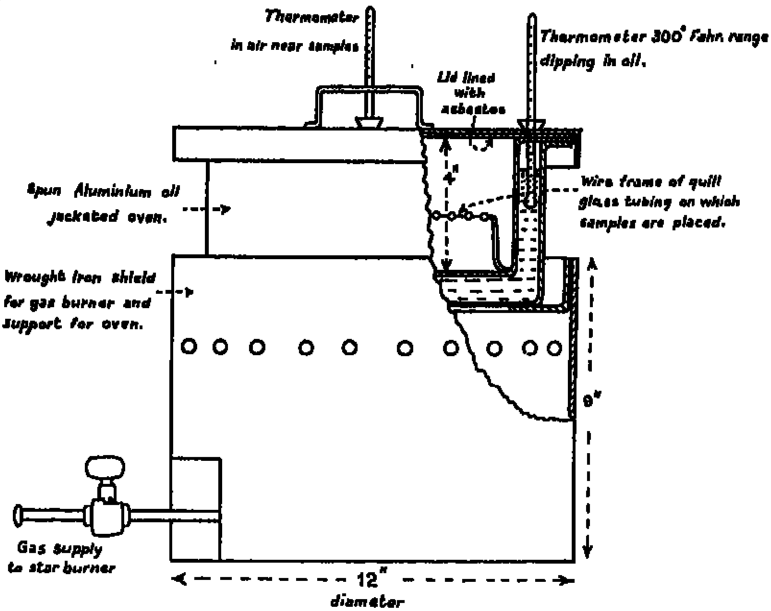


FIG. 43.—Oven Used for Dry Heat Test of Rubber.

information occasionally that obviates an expensive analysis being made.

Some of the earthy fillers that are used, especially in cable rubbers, increase the speed at which vulcanisation proceeds, and are known as accelerators. The following list of materials used as fillers is taken from Porritt's "Chemistry of Rubber":—

(*a*) Accelerators of Vulcanisation.—Litharge, calcium hydrate, magnesium oxide or carbonate.

(*b*) Colourless Fillings.—Whiting, barium sulphate, lithopone (finely divided barium sulphate and zinc sulphide), French chalk, and zinc oxide.

(*c*) Coloured Fillings.—Antimony sulphide, arsenic sulphide, mercuric sulphide, red lead, lead peroxide, ferric oxide, chromic oxide,

lead chromate (cold cure), ultramarine Prussian blue (cold cure), graphite, and lamp-black.

(*d*) Organic Fillers.—Paraffin wax, pitch, rosin, tar, and rubber substitutes (white and brown).

The white and brown substitutes are said to be vulcanised oils such as colza, linseed, and other vegetable oils, treated either with sulphur chloride, or, after heating to 200° C., with flowers of sulphur.

Post Office Types of Vulcanised India-rubber Covered Cables.—The details of the principal types are shown in the following table:—

Item No.	Number and Weight per Mile of Wires.	Maximum Overall Diameter of Lead Sheath.	Thickness in Mils—		Maximum Resistance in Ohms per Mile—		Minimum Insulation Resistance Mile-megohms.	Use.
			Of Pure Rubber Coating.	Of Total Dielectric.	Before Cabling.	Of Finished Cable.		
		Mils.						
1	16 wire / 20 lb. quad	—	10	35	44·29	44·73	2000	Aerial cable for temporary use during diversions.
2	38 wire / 20 lb. twin	—	10	35	44·29	45·18	2000	Do.
3	2 wire / 20 lb. twin (twisted)	—	10	35	44·29	44·73	2000	For making pothead joints on aerial cables.
4	2 wire / 20 lb. (flat, untwisted)	—	10	35	44·29	44·29	2000	For subscribers' leads where lead-covered cable is unsuitable.
5	1 wire / 40 lb.	200	6	35	22·15	22·15	500	For primary battery leads and leading in from insulators.
6	2 wire / 40 lb. (thin)	270	6	Minimum diameter 100 (over tape)	22·15	22·37	200	For leading into pole test boxes from underground and to insulators.
7*	2 wire / 20 lb.	—	6	Thickness 35	44·29	44·73	2000	Aerial cable for temporary use during diversions.
8*	4 wire / 20 lb.	—	6	35	44·29	44·73	2000	Do.

* These cables have galvanised steel suspending wires consisting of a strand of seven No. 22 S.W.G. galvanised steel wires having a breaking stress of not less than 80 tons per square inch.

Dielectric.—The dielectric consists of three layers, the first next to the tinned conductor is of pure rubber, the second, or separator, is of vulcanised rubber, generally compounded with zinc oxide, and the third, or jacket, is of vulcanised rubber, and usually contains litharge (lead monoxide). The colours of the layers are (1) brown; (2) yellowish white; (3) black. The first layer is of pure rubber without any sulphur, because the latter is liable to corrode any untinned part of the conductor. Pure rubber will act chemically on bare copper with formation of black copper oxide, and the action is increased if there is any sulphur in the rubber, but if the wire is satisfactorily tinned there is practically no action, even if the rubber contains a fractional percentage of sulphur. The function of the litharge in the jacket rubber is to expedite the vulcanising process, but incidentally it causes the jacket rubber to be black by forming lead sulphide during the vulcanising process. If accelerators other than litharge are used, it is the practice to make the jacket rubber black by adding a little high grade vegetable black (carbon). The rubber is vulcanised after it is put on the wire, so that the jacket and separator rubbers are vulcanised at the same time. The total dielectric should contain not less than 45 per cent. of rubber of the best quality. Rubber substitute and remanufactured rubber should not be used. India-rubber covered cotton tape is lapped spirally over the jacket rubber before vulcanisation, and is vulcanised with the dielectric.

16-Wire aerial cable is made up of four quadruple cores, the adjacent cores being of the same colour, viz., two red and two black, the four cores being laid up round a centre of tanned jute. The lay of the cores in the quadruple cores is 5, 6, 7, and 8 inches respectively, and the lay of the cable 12 inches. This cable is wormed with tanned jute to protect it from injury during the braiding process.

38-Wire aerial cable is laid up into 19 pairs and then cabled. The centre consists of one pair with a 4-inch left-hand lay. Round this 6 pairs are laid with a 10-inch right-hand lay, the lays of the pairs being 5, 6, and 7 inches repeating, whilst the second layer consists of 12 pairs laid up with a 14-inch left-hand lay, the lays of the pairs being 4, 5, 6, and 7 inches repeating. Both the 16- and 38-wire cables are covered with an ozokerit coated cotton tape, laid on spirally and then braided with Russian hemp yarn prepared with ozokerit compound. The complete cables are finally coated with ozokerit compound.

The dielectric of the $\frac{\text{2 wire}}{\text{20 lbs.}}$ (twin) and $\frac{\text{2 wire}}{\text{20 lbs.}}$ (flat) is lapped with a waterproof tape and then strongly braided with cotton, the braiding being impregnated with ozokerit. One braiding is red, the other black.

The dielectric of the $\frac{\text{1 wire}}{\text{40 lbs.}}$ is lapped with a thin proofed tape, and the rubber and tape vulcanised together. The thickness of the lead sheath should not be less than 27 mils.

The dielectric of the $\frac{2 \text{ wire}}{40 \text{ lb.}}$ is lapped with a thin proofed tape, and the rubber and tape vulcanised together. The thickness of the lead sheath should not be less than 30 mils.

The dielectric of the $\frac{2 \text{ wire}}{20 \text{ lbs.}}$ and $\frac{4 \text{ wire}}{20 \text{ lbs.}}$ is lapped spirally with proofed cotton tape, and the rubber and tape vulcanised together. Half the cores are coloured red, the others black. The taped cores, after vulcanising, are coated with ozokerit compound.

Tests.—(1) Samples of the complete dielectric, after the tape has been removed, are subjected to the heat tests previously referred to, but the moist heat test at 320° F. is for three and not four hours for these cables. Three days after the heat tests the samples should bear stretching to two and a half times their original length, be kept stretched to this length for twenty-four hours, and then return to within 25 per cent. of their original length within six hours of being released.

(2) Fresh samples of the complete dielectric, after the tape has been removed, should bear being stretched to three times their original length—usually 2 inches stretched to 6 inches—be kept stretched to this length for twenty-four hours, and then return to within 25 per cent. of their original length within six hours of being released.

(3) The tinning of the conductor should be tested by bending the wire into a loop, the radius of which should be between twelve and fifteen times the diameter of the wire. The conductor is cleaned with alcohol or ether to remove any grease, and is then immersed for one minute in hydrochloric acid having a specific gravity at 60° F. of 1·088 (55 per cent. of acid of specific gravity 1·16). The conductor is then rinsed in clean water and immersed for half a minute in a solution of sodium sulphide, having at 60° F. a specific gravity of 1·142 (about 25 grammes per 100 c.c. of water). The conductor is then washed in water and examined under a hand lens. The 20-lb. conductors should withstand this process being performed eight times, and the 40-lb. conductors seven times, without there being a visible blackening effect. A further sample of the conductor is bent round a rod having a diameter equal to four times the diameter of the conductor, and then treated as above for one cycle. It should withstand this test without any apparent blackening.

(4) The organic matter extractable with acetone should not exceed 5 per cent. of the total dielectric. The rubber resins should not exceed 2 per cent. and the free sulphur should not exceed 0·75 per cent. of the total dialectric. The amount of organic matter extractable with semi-normal alcoholic potash from the residue after extraction with acetone should not exceed 1 per cent. of the total dielectric. The inorganic matter or fillers should not exceed 54 per cent. of the total dielectric. The fillers can be roughly estimated by ascertaining the percentage of ash left after thorough incineration. If desired, the fillers can be estimated as follows. The

rubber is cut up very fine, and 2 grammes are put into a 200 c.c. flask with 70 c.c. of kerosene. The flask is connected to a reflux condenser and heated till the kerosene begins to boil. The kerosene is kept simmering for about two hours until all the rubber goes into solution. The solution is cooled, allowed to stand for a few hours, the liquid decanted, and the residue washed two or three times with 90 per cent. benzol on a tared filter paper.

(5) The free or uncombined sulphur should not exceed 0·75 per cent. of the total dielectric. The sulphur combined with the rubber should be not less than 1·25 per cent. nor more than 1·75 per cent. of the total dialectric.

The free sulphur is soluble in acetone, and is determined by evaporating the acetone extract obtained in (4) above to dryness. A little sodium acetate is added to fix the sulphur, and about 30 c.c. of nitric acid (specific gravity, 1·5) added. If all the sulphur does not dissolve, a few drops of bromine are also added. Boil till excess of nitric acid is nearly driven off, dilute, neutralise with NH_4OH, and acidify with HCl. Precipitate with barium chloride and weigh as barium sulphate. A method of estimating the total sulphur is given later under ebonite.

(6) The tensile strength of the complete dielectric should be not less than 800 lbs. per square inch.

(7) The insulation resistance of the core in water at 60° F., after immersion in water at this temperature for twenty-four hours, should be not less than 2000 mile-megohms after one minute's steady electrification, and the electrostatic capacity per mile should be not greater than 0·35 microfarads. Items 5 and 6 have no stipulation as to capacity, and the insulation is 500 and 200 mile-megohms respectively.

Since the insulation resistance is calculated after the battery has been applied for one minute, it follows that if the conditions are such as to slow down the rate at which the electrification proceeds, the apparent insulation resistance at one minute will be correspondingly decreased. If the cable is tested without immersing in water, and the rubber is in the normal dry condition, the electrification is slowed down very considerably, and at the end of one minute the apparent insulation resistance is much lower than would be found if the cable were tested in water. This is a well-known effect, but it is a little surprising at first sight. In a series of tests on the same coils the apparent insulation increased, as the coils were damped more and more, the highest value being obtained after immersing completely in water. The tests were not taken immediately after each other, but daily, the conductor being earthed for twenty-four hours between each two tests. It is sometimes convenient to take an insulation test of india-rubber cables containing a large number of wires in the dry condition, or with the aid of wet blankets, but such tests always show comparatively low insulation resistance owing to this phenomenon of slow electrification. The soaking of the rubber coating in water for twenty-four hours is

not recommended by some authorities, as they consider that th rubber deteriorates in the process, and if the cable is to be used i dry situations, there seems to be some justification for the contention but for aerial purposes it is desirable to ensure that there are n defects in the covering, and the water test is in these circumstance the only safe course to follow.

Ebonite.—The highest grade of ebonite is made of fine hard para rubber and sulphur only, the percentage of sulphur ranging from 30 to 35 per cent. The rubber and sulphur are intimately mixed on the mixing-rolls, and the vulcanisation takes place in steam chests, but the steam does not come into direct contact with the rubber. French chalk is largely used as a protection to the surface of the rubber, and to prevent neighbouring pieces sticking together. Ebonite made according to this formula has a very high dielectric or puncture strength, the Admiralty specification calling for 125,000 volts per millimetre of thickness. If the vulcanisation process is carried too far the ebonite is brittle and short. It is an interesting fact that more than 32 per cent. of sulphur in combination with the rubber has not so far been obtained. This percentage agrees with the empirical formula $C_{10}H_{16}S_2$. Thin strips of ebonite, when successfully vulcanised, exhibit the flexible and elastic properties that are usually found in whalebone, and ebonite of this kind gives a good long curly shaving when cut with a sharp knife. The terms "ebonite," "vulcanite," and "hard rubber" are really synonymous, the first term being in general use in the English telephone industry, vulcanite in the tobacco pipe-stem trade, whilst hard rubber is in fairly general use in America. Ebonite will take a mechanical polish, and other things being equal, the better the quality the brighter the polish. The lower grades of ebonite are made from cheaper rubbers and fillers of the organic type, such as vulcanised oil, bitumen, etc., are used. Ebonites containing appreciable quantities of oil substitute, etc., are found to cut more easily than "all rubber" ebonites, and for certain purposes these qualities are largely used as the wear on the cutting tools in machining high-grade ebonite is very considerable. Sometimes, however, the amount of substitute is excessive, and if the material in use is subjected to attrition or abrasion, a relatively short life is the result. The Post Office Specification provides for five grades or qualities of ebonite, four of which are "all rubber" ebonites and the fifth is not. For the best, or **A quality** rubber of the best quality is stipulated, with not more than 30 per cent. of sulphur. Not more than 5 per cent. of the whole weight may consist of sulphur in the free or uncombined condition. The total percentage of resins extractable with acetone must not exceed 5 per cent. After extraction of the resin, free sulphur, and matter saponifiable in a semi-normal alcoholic solution of potash, the ebonite of A quality must not yield more than 4 per cent. of matter extractable with pyridine, the extraction being continued for one hour in a hot tube extractor. The ash left by the ebonite after thorough incineration must not

exceed 2 per cent. The ebonite must be vulcanised so as to leave it tough and elastic and capable of withstanding considerable blows, such as small pieces (e.g. 2″ × 2″ × ⅛″, or pieces moulded as ear-pieces for telephone receivers) would experience in falling upon a stone floor from a height of 15 feet. The cantilever strength should be not less than 20 lbs. when tested at a leverage of 2 inches, the cross-section being ¼ inch square.

B quality is made of rubber of good quality and sulphur. The sulphur must not exceed 30 per cent., of which not more than five may be in the free or uncombined condition. Cantilever strength not less than 16 lbs. when tested on sample similar to A quality. Resins extractable with acetone not to exceed 10 per cent. and ash 3 per cent.

C quality is made of rubber and sulphur, and not more than 5 per cent. of free sulphur is allowed. It is stipulated that this quality must be free from inorganic loading material, and be suitable for use in large pieces where mechanical strength is not of first importance, but must be capable of being satisfactorily drilled and tapped. Cantilever strength not less than 12 lbs. when tested on sample similar to A quality. The specific gravity of C quality must not be higher than 1·22 at 60° F.

D quality (red) is made of rubber of good quality, sulphur, and vermilion. Cantilever strength as in A quality must not be less than 12 lbs., and the ebonite must not contain more than 45 per cent. of vermilion. The total sulphur, including that in the vermilion, must not exceed 23 per cent., of which not more than five may be in the free or uncombined condition. Resins extractable with acetone must not exceed 7 per cent.

E quality must not contain more than 5 per cent. of free sulphur. Cantilever strength not less than 10 lbs. when tested as sample in A quality. Ash not more than 10 per cent.; specific gravity at 60° F. not higher than 1·31.

The mechanical tests are made at a temperature of approximately 60° F.

All qualities must be tough and well vulcanised and capable of taking a good mechanical polish. They must also soften sufficiently in boiling water to allow of their being readily bent to any desired shape, and they must be homogeneous and free from grit and metal dust.

It is well known that **ebonite dust** obtained by grinding scrap ebonite to a fine state of division somewhat resembling snuff is used in the manufacture of ebonite, and there seems to be good reason for the practice. The resulting ebonite is difficult to distinguish from ebonite made entirely of raw rubber and sulphur, and probably the only means of detecting the inclusion of ebonite dust would be by microscopical examination. There seems to be every reason why the scrap ebonite should be used up, and there is no valid argument against its use for ordinary purposes. Possibly the mechanical polish will be somewhat duller than the highest grade ebonite, but

for telephone purposes this is not a matter of great importance. The following is a description of the routine method of examining chemically Post Office A quality. It should be noted, however, that it does not claim to be a complete analysis, and is only applicable therefore to ebonite of high quality. If added resins or organic solids such as finely divided wood, etc., are suspected, a complete analysis would be necessary, and the method described in Weber's "Chemistry of India-rubber" would form the basis of procedure. In the first place, the cantilever strength of the sample would be determined, and as it is unlikely that the specified strength would be obtained with ebonite containing added resins, etc., this test gives some indication of the quality. Fig. 44 shows the extraction apparatus.

About 5 grammes of the ebonite in a finely divided state are dried in an oven at 100° C. until the ebonite ceases to lose weight.

Acetone Extraction.—Two grammes of the dried ebonite are put into the extraction thimble A, and the thimble put into the extraction tube B, and the tube connected to a reflux condenser. A 200 c.c. tared flask (C), containing 50 c.c. of pure acetone, is connected to the other end of the extraction tube B. The acetone is boiled continuously for eight hours at such a rate as will allow the acetone to condense and produce a steady stream through the thimble A. The thimble A is then placed in an oven and dried at 100 °C., cooled in a dessicator, and weighed. The loss in weight is recorded as the weight of resin and free sulphur. The residue (I.) in the thimble is subsequently treated with alcoholic potash.

The acetone is evaporated from the tared flask C, and the flask with its residue weighed. The weight of this residue (II.) should agree, within about 0·2 per cent., with the loss of weight calculated from the preceding process. Residue II. is treated with nitric acid (1·5 specific gravity) and bromine until all the sulphur is oxidised, diluted with 100 c.c. of boiling water, neutralised with ammonia, acidified with hydrochloric acid, and filtered. The solution is boiled with a slight excess of 10 per cent. barium chloride solution, added gradually, and the precipitated barium sulphate filtered off, dried, and weighed.

The weight of barium sulphate multiplied by 6·87 is taken as the percentage of free sulphur in the ebonite.

Residue I. is boiled in 100 c.c. of freshly made $\frac{N}{2}$ alcoholic potash for four hours in flask C, attached direct to a reflux condenser. The residue is filtered and washed once with absolute alcohol, twice with boiling water, twice with 5 per cent. hydrochloric acid, then with boiling water till free from acid, and finally with absolute alcohol. The residue (III.) is dried at 100° C., cooled in a desiccator, and weighed. The difference in weight between residue I. and residue III., expressed in grammes and multiplied by 50 (fifty), is taken as the percentage of saponifiable matter in the ebonite.

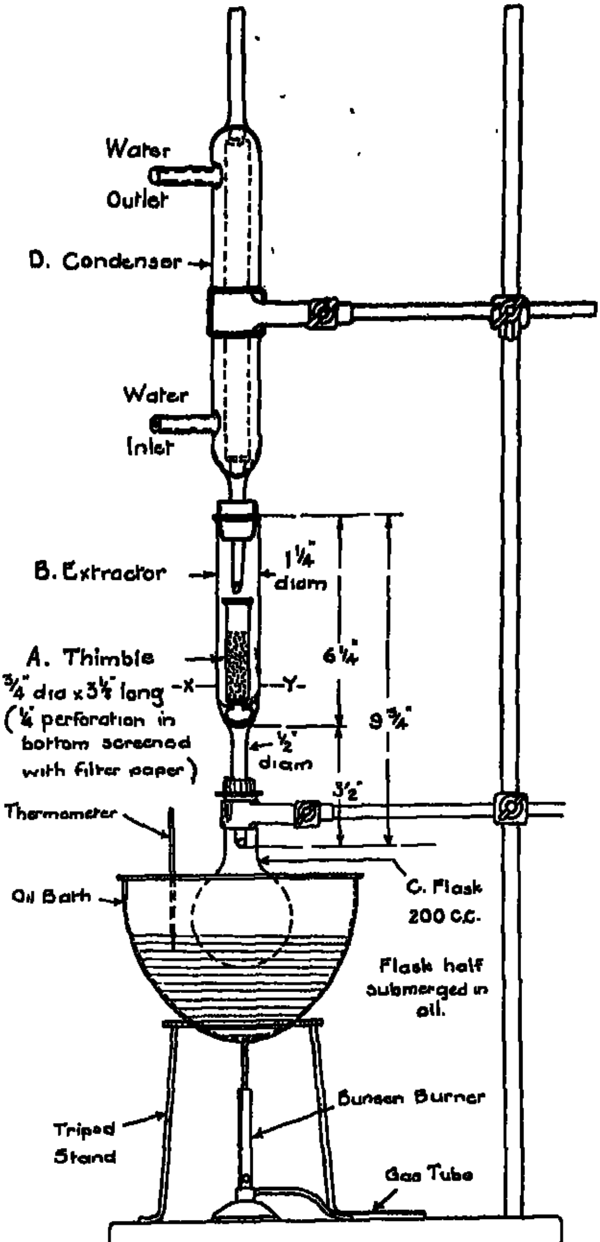


FIG. 44.—Extraction Apparatus used in Testing Rubber.

The solution of saponifiable matter in $\frac{N}{2}$ alcoholic potash is acidified with dilute sulphuric acid and extracted with ether. The ether is evaporated and the residue weighed. The weight of this residue should agree within about 0·4 per cent. with the difference in weight of residues I. and III.

Residue III. is replaced in thimble A, the latter placed in tube B, and connected to the apparatus in the same way as for the acetone extraction described above, except that 50 c.c. of pure pyridine is placed in flask C instead of acetone. This pyridine is boiled and condensed continuously for one hour, and the apparatus is then allowed to cool. Flask C is removed and a similar flask containing 30 c.c. of acetone is connected to the apparatus. The acetone is boiled and condensed for fifteen minutes, so as to remove the traces of pyridine in the residue (IV.). Residue IV. is dried at 100° C., cooled in a dessicator, and weighed. The difference in weight between residue IV. and residue III., multiplied by 50 (fifty), is taken as the percentage of pyridine extract.

The pyridine containing the dissolved part of residue III. is distilled off and the residue V. washed with acetone into a tared porcelain basin. The residue V. is dried at 100° C., cooled in a desiccator, and weighed. The weight of residue V. should be within 0·3 per cent. of the difference of weights of residues III. and IV. found above.

Total Sulphur.—0·25 gramme of the dried sample referred to in paragraph 1, is thoroughly mixed with 7 grammes of an oxidising mixture consisting of equal weights of sodium carbonate and manganese dioxide. Half a gramme of the oxidising mixture is placed at the bottom of a porcelain crucible, the sample of ebonite mixed with the oxidising mixture as above is placed on this, and half a gramme of the oxidising mixture on the top, i.e. 8 grammes of oxidising mixture are used. Heat is gently applied by means of a Bunsen burner for fifteen minutes, and the crucible is then raised to a red heat, and maintained at this temperature for one hour. The resulting sodium sulphate is dissolved in boiling water, the solution acidified with hydrochloric acid and treated with an excess of 10 per cent. barium chloride solution, added gradually. The precipitated barium sulphate is filtered off, dried in a dessicator, and weighed. The weight of barium sulphate, multiplied by 54·96, is taken as the percentage of total sulphur.

Note.—A blank determination should be made to ensure that any sulphur which may be present in the manganese dioxide is allowed for.

Gutta-Percha.—Gutta-percha is obtained from a milky fluid or latex found in the bark of certain trees of the *Sapotaceæ* family in the Malay district, and Singapore is the principal centre of the gutta-percha trade. The more important trees yielding this latex are *Isonandra gutta*, *Dichopsis oblongifolia or Palaquium*, *Payena Leerii*, *Dichopsis polyantha*, and *Dichopsis Maingayi*. The milky fluid, however, does not flow freely as in the case of rubber and

balata—to be referred to later—and Dr. Obach states that the Malay Getah collector invariably fells the tree, chops off the branches, and rings the bark at distances of 12 to 18 inches all along the trunk. The milky fluid fills the grooves cut in the bark, and with the better kinds of trees the fluid quickly coagulates, and is subsequently scraped off with the aid of a knife. In the case of inferior trees the latex requires a much longer time to curdle, and has to be collected in a receptacle of some sort, such as a cocoanut shell or the spathe of a palm placed under the trunk. The latex is then taken to the huts and gently boiled, either by itself or with the addition of water. Gutta-percha consists of a hydrocarbon and two natural resins, Albane and Fluavile. The hydrocarbon is of the terpene series, having the same empirical formula, $C_{10}H_{16}$, as the rubber hydrocarbon, but it differs from rubber very markedly in physical properties. The pure hydrocarbon is called Gutta. When heated above 150° F. it softens and is very plastic, retaining the shape given to it at this high temperature after it cools. Pure caoutchouc, on the other hand, changes very little when warmed in this way. The resins Albane and Fluavile appear to be oxidation products of the hydrocarbon, and the proportion of resins to gutta varies considerably in commercial samples, the best showing as little as 10 per cent. of resins, while the worst may reach as high as 65 per cent. Dr. Obach states that the Malay word "Getah," which is now rendered "Gutta," simply means the viscous exudation of a plant, and "Getah Taban" the secretion of that particular kind of tree called Taban. As it is from this tree and not from *Pertja* that the gum now called gutta-percha is derived, it is to be regretted that the wrong name was given to it on its first introduction into Europe. Practical men in England never refer to it as "gutta perka," although this pronunciation is used in certain circles, but always as "Gutta Pertja." The chemical and physical examination of the material, from a cable manufacturer's point of view, is fully described in Dr. Obach's Cantor Lectures before the Royal Society of Arts, and the reader who desires a full description of the material from the manufacturing point of view is recommended to read them. From a telegraph and telephone engineer's point of view, it is only necessary to refer briefly to the methods adopted for examining the quality of the material after it has been applied to the conductor. It may perhaps be worth while briefly to mention, however, the processes through which it passes before being applied to the wire. Owing to the crude methods employed in its collection, the commercial article may contain varying amounts of extraneous matter such as pieces of bark, wood-chips, stones, and other impurities, together with a fairly large amount of imprisoned water. For insulating purposes it must be thoroughly freed from all solid impurities, and this is done by washing the gutta-percha at a fairly high temperature and subsequently kneading or masticating it. The cleaned gutta-percha is sometimes driven through a fine-meshed gauze to ensure its freedom from solid particles. In carrying out the washing and cleaning

process there is a certain amount of oxidation produced, and it is important that this process should not be carried to excess, or the material will permenently deteriorate. The usual tests applied to gutta-percha are as follows :—

(*a*) Determination of resin.
(*b*) Tensile strength of extracted gutta at 70° F., and also at 110° F.
(*c*) Kneading and stretching into thin films.
(*d*) Electrical tests (electrostatic capacity, dielectric loss at telephone frequency, insulation resistance, electrification).

(*a*) The approximate percentage of resin is most conveniently determined by extracting it from the gutta-percha with petroleum spirit. Two grammes of the gutta-percha are cut up into small pieces and placed in a stoppered bottle containing 200 c.c. of petroleum spirit. After twenty-four hours the resin will have gone into solution, leaving the hydrocarbon (gutta) as residue. The liquid is decanted as far as possible, and the residue caught on a tared filter paper. Gentle heat is applied to drive off the remainder of the petroleum spirit, and the filter paper and its contents weighed. The loss of weight is expressed as a percentage of the 2 grammes, and is assumed to be resin.

The method, of course, is not an accurate determination, but it is generally near enough for the purposes of the telephone engineer, because the exact percentage of resin is not of vital importance to him, but only an indication of the grade of gutta-percha under examination. A more accurate determination would include the estimation of (*a*) moisture and (*b*) extraneous matter (dirt). In this case two samples of 2 grammes each would be used—one dried in a vacuum till it ceased to lose weight, and the other would be put into an extraction apparatus similar to that used for rubber and extracted with chloroform. The gutta and resin go into solution, leaving the dirt in the thimble. The gutta is subsequently precipitated from the chloroform by the addition of acetone, in which it is insoluble. The gutta is dissolved a second time in chloroform and again precipitated with acetone, to ensure that no resin has been occluded in the precipitate. The resin may be as low as 10 per cent., and in low grades of percha over 50 per cent.

(*b*) For the tensile test about 5 grammes of the gutta-percha is put in a stoppered bottle and the resin extracted with about 250 c.c. of petroleum spirit. The extraction is complete after about twenty-four hours, and the gutta is ready for moulding or rolling into a suitable shape for the tensile test. The gutta is quite free from any stickiness—which was due to the presence of the resin—and where facilities for moulding are available, this method of preparing the specimen is recommended, but in ordinary laboratories where moulding facilities are usually not available, the rolling method is convenient and fairly reliable. The rolling equipment consists of two ¾-inch mahogany boards faced with brass, machined to the

section shown in Fig. 45. So that the gutta sample after rolling is of the shape shown in Fig. 46.

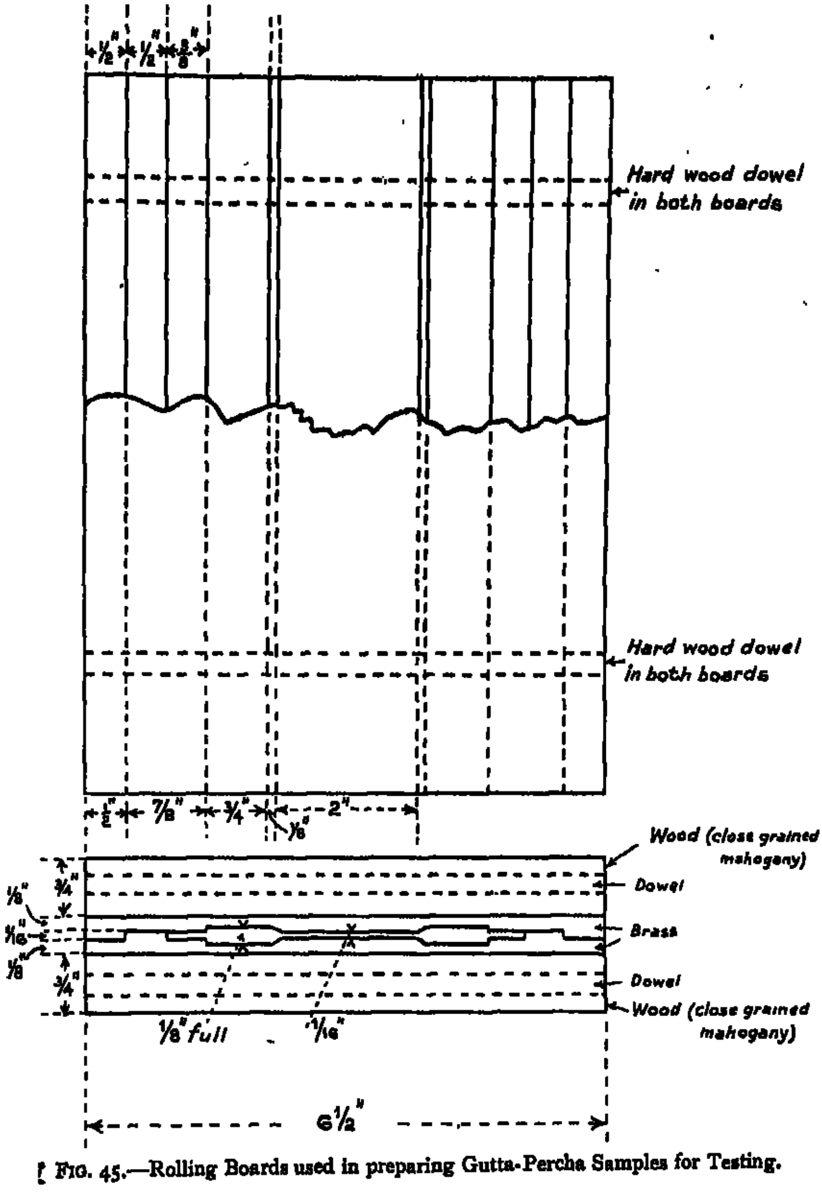


FIG. 45.—Rolling Boards used in preparing Gutta-Percha Samples for Testing.

To facilitate the rolling of the gutta, it is necessary to warm it in water at about 160° F., and to pour a little of the water on the brass faces of the boards, to prevent the gutta from cooling while the rolling is done. It is desirable to keep the temperature of the water within fixed limits if the results of tests are to be comparable. The sample is then placed in water at 75° F., and kept at this temperature for three hours, to ensure that the gutta is at a uniform temperature. Fig. 47 shows a set of suitable dies and holders for gripping the sample. A similar set is used for gripping the other end of the sample.

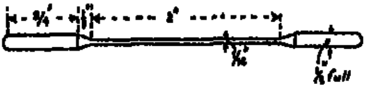


Fig. 46.—Shape of Test Sample of Gutta-Percha.

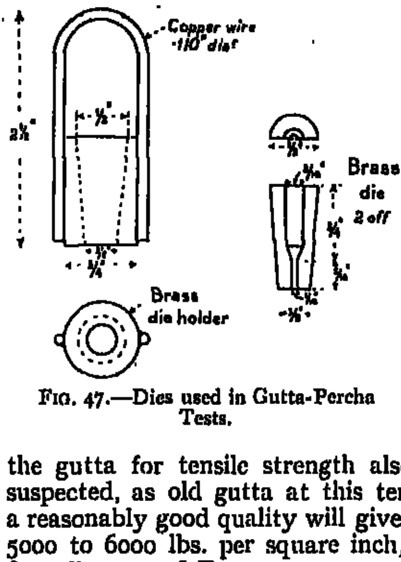


Fig. 47.—Dies used in Gutta-Percha Tests.

The test is made under water at 75° F., the bottom of the tank being fitted with a hook to which the bottom die-holder is attached, whilst the top die-holder is attached to the hook of a spring balance. The other end of the balance is attached to a straining cord, which passes over an overhead pulley. The diameter of the middle portion of the sample is accurately gauged with a micrometer screw gauge before test, and also at the point of fracture after test. The reduction in area on reasonably good gutta is generally about 80 per cent., and the breaking weight 7000 to 8000 lbs. per square inch. It is advisable to test the gutta for tensile strength also at 110° F. if a low grade is suspected, as old gutta at this temperature is very weak, whereas a reasonably good quality will give a breaking weight equivalent to 5000 to 6000 lbs. per square inch, assuming that it gave 7000 to 8000 lbs. at 75° F.

(*c*) A piece of the unextracted gutta-percha—about enough to mould into the size of a walnut—is put into boiling water and left there for two minutes. It is then taken out and kneaded between the fingers, folding it over and over until it cools to a temperature which will permit of its being stretched into a thin film about 5 inches wide and 7½ inches long, and stuck on a sheet of white paper. A little practice is required to obtain the necessary skill to perform this operation successfully, but more information as to the quality of the gutta-percha can be obtained from this kneading process than may seem feasible at first sight. Old and resinous gutta-perchas assume the consistency almost of birdlime when left in boiling water for two minutes, whereas high-grade perchas remain fairly hard and nervy, and require to be drawn into a film almost immedi-

ately they are taken out of the water, as they set very quickly. A low-grade percha can, on the other hand, be kneaded for several minutes before drawing out into a film; in fact, as a general statement, it may be said that the easier the gutta-percha will draw into a film the more resinous and lower in quality it is likely to be. Experience, however, is desirable in this case as in many others, and in coming to a decision it is advisable to follow a systematic method, viz., draw the samples first and make notes of the qualities as judged from the kneading. Compare these notes with the tensile test of the gutta and the percentage of resin. If the results confirm each other the probability is that a correct estimate of the quality has been made. The tests are only approximations, but they are quite satisfactory for comparing samples purporting to be of equal quality.

(*d*) In the electrical tests it is significant to note that some of the best gutta-percha shows a relatively low insulation resistance and electrification; in fact, a high resistance is regarded by some authorities as indicating a poor quality; 300 to 400 mile-megohms with 2 to 3 per cent. electrification have frequently been obtained from a high-grade gutta-percha. For methods of determining dielectric loss, the ratio of leakance to capacity, and other measurements at telephonic frequencies, the reader is referred to Volume I. in this series.

With regard to the durability of gutta-percha, it may be said that it depends almost entirely upon the conditions under which it is used. Deterioration is almost entirely due to oxidation with the formation of resins, sometimes referred to as Spiller's resins, as Spiller was the first investigator to draw attention to this fact. In the early days of telegraphy very large quantities of gutta-percha covered wire were laid underground in the London district, and although the highest obtainable grade of gutta-percha was used for the purpose, the life of the cables was relatively short, seldom exceeding ten to twelve years. There were exceptions to this general average, but they were confined to the cables laid in the very early days of the industry. A sample of the gutta-percha, taken from a cable known to have been in use for nearly fifty years in the London district, on analysis showed over 70 per cent. of gutta, and the extracted gutta was found to have considerable toughness even at this age. On the other hand, when gutta-percha is used for submarine purposes, the oxidation is arrested, and it is difficult to estimate the life of gutta-percha under these conditions, as there appears to be little or no deterioration. It is usual, therefore, to take into consideration the conditions that a gutta-percha cable will be required to withstand in deciding upon the quality of gutta-percha to be used, and to employ only the highest grade for underground work and medium grades for submarine. It is evident that if deterioration is due to oxidation with the formation of resin, underground conductors should be covered with a gutta-percha containing the lowest practicable percentage of resin, but for submarine purposes the percentage of resin is not of the same importance, and

other factors, such as dielectric leakance at high frequencies, have to be considered.

Balata is obtained in much the same way as gutta-percha from the "Bullet Tree," belonging to the same botanical family, and is found in Jamaica, Trinidad, Venezuela, British Guiana, etc. Dr. Obach says that the latex is much more liquid than the gutta-percha latex, and that the tapping of the latex is carried out on somewhat the same lines as are employed in tapping rubber trees. Balata resembles gutta-percha in most of its physical properties, but it is somewhat softer, and the extracted gutta is not quite so tough. Balata is generally of a lighter colour and more translucent than gutta-percha, and the difference in appearance when the two are drawn out in films is most characteristic at the top and bottom edges of the film, gutta-percha showing a tendency to redness, whereas balata is generally of a yellowish-brown or dull red colour. The colour of both gutta-percha and balata is affected temporarily by over mastication and continued boiling in water, both becoming somewhat lighter in colour. Balata fell into disfavour some thirty years ago as a covering for telegraph conductors, as its life in the London underground was very short, but in recent years it has been found to possess properties superior to gutta-percha for telephone cables, owing to its lower leakance, and special mixtures containing balata are now being used for submarine purposes. Messrs. Siemens & Halske, in their patent No. 10053 (1912), claim that whereas the ratio of leakance to capacity for gutta-percha is 100, the same ratio for pure balata is only 10, and since this ratio is in the numerator of the fraction expressing the attenuation constant of cables, the improvement in transmission by the use of balata in the place of gutta-percha is considerable. There appears to be no action between a bare copper wire and its gutta-percha covering, but with rubber there is considerable action, with deterioration of the rubber, even when the rubber is not vulcanised. A somewhat similar action appears to take place with balata, and it is the practice, therefore, to tin the conductors when they are insulated either with rubber or with balata, but to use untinned copper with gutta-percha. The tinning of the conductor completely overcomes the trouble, but it is important to see that the tinning is well done and continuous. Balata and gutta-percha are not subjected to any vulcanising process for cable purposes, and they are not compounded with earthy materials, as is the case with rubber, but are used in their natural condition. It may be safely assumed that cable makers blend different grades of gutta-percha in the washing and masticating processes, and that any particular cable will not, as a rule, be covered with a material taken from one source, unless they have to meet the special wish of the purchaser as an exceptional case.

Balata is generally tested in the same way as gutta-percha, but yields, as a rule, somewhat lower results in the tensile test, and about the same result with regard to the percentage of resin as a medium grade gutta-percha.

CHAPTER VII

CLAY AND CLAY PRODUCTS

CLAY is the name given to a large number of substances which occur in nature, all of which show in varying degrees the property of becoming plastic when in a moist condition. The composition of these substances varies enormously, but the essential constituent appears to be a hydrated silicate of alumina represented by the chemical formula Al_2O_3, $2SiO_2$, $2H_2O$, which is referred to in the ceramic industry as pure clay. It will be seen from the formula that it contains two molecules of combined water or water of crystallisation, and while this combined water is retained the substance, on being moistened, becomes plastic. If the pure clay is heated above 700° C., the combined water is driven off and the resulting aluminium silicate no longer possesses the property of becoming plastic when moistened with water, no matter how fine the material may be ground. In "A Treatise on Ceramic Industries," by E. Bourry, it is stated that pure clay is in the form of lamellar crystals, so that the grains are closer together than they would be if they were polyhedral or spherical, and that all bodies which are made up of laminated particles must become plastic when they are reduced to a sufficiently impalpable powder and moistened. This view is borne out to a considerable degree by Professor Ewing's experiments on the plastic condition of steel under repeated stresses. He showed that when the plastic stage was reached the material developed slip-bands in the crystal grains. Under high magnification the development of the slip-bands across the crystals was studied, and it was shown that the slip-bands developed quite independent of the direction of the stresses, being differently orientated in neighbouring crystals, and the actual slip along the cleavage planes of the crystal was proved by oblique illumination. At a very high temperature different kinds of glass exhibit the same property of plasticity, and they can be modelled, of course, into most beautiful shapes by the skilled glassworker. The cause of plasticity, therefore, appears to be in process of being completely explained.

The purest form of clay found in nature is kaolin or china clay, so named because it was originally obtained from China, but English supplies are now obtained almost exclusively from Cornwall. It appears to be the product of the decomposition of granite rock. Granite consists of three main constituents—felspar, quartz, and mica. The quartz (SiO_2) and mica (a double silicate of an alkali,

Na, K or Mg, and aluminium) do not apparently undergo any process of decomposition, but the felspar does. There are many kinds of felspar, but the most common and important is known as orthoclase, and has the following approximate composition:—

Silica (SiO_2)	64	per cent.
Alumina (Al_2O_3)	19	„
Potash (K_2O)	17	„

By the action of the weather the potash is probably eliminated in the form of potassium carbonate, which is soluble in water, and the silica and alumina are left in the form of kaolin. The average composition of Cornish china clay or kaolin is approximately:—

Silica	47	per cent.
Alumina	40	„
Combined water	13	„

In Hurst's "Painters' Colours, Oils, and Varnishes" a detailed description of the method of winning china clay in Cornwall will be found, and it must suffice here to say that it occurs in large deposits along with the other constituents of undecomposed granite, the china clay usually amounting to about 20 per cent. of the whole deposit. It is separated from the mica and silica by levigation, a stream of water carrying the finely divided china clay in suspension, whereas the mica and silica are more readily deposited in launders provided to catch the larger and heavier particles. The china clay in suspension in the water, after standing in pits for some time, settles to the bottom. The water is then run off and the clay dug out and dried. It is a fine white powder, and moderately plastic when moistened. In recent years a process of depositing clay electrically has been developed, and Dr. Ormanby, in a paper on "Some Practical Applications of Electric Endosmosis and Cataphoresis," read before a joint meeting of the Faraday Society and the Physical Society of London in October, 1920, the report of which is published by H.M. Stationery Office in a volume dealing with the physics and chemistry of colloids, says: "In treating a very pure specimen of a well-washed English china clay by the Osmose process, it has been found possible to deposit as much as 6833 kilogrammes of dry clay substance with 11·8 kilowatt hours of current when working at 50 volts pressure. It is interesting to regard this deposition of clay by direct electric current as though we were dealing with the deposition of copper from a solution of one of its salts. On the basis of the figures given above we should have to assume that the equivalent weight of china clay was of the order of 700,000, and that where a given current would deposit 1 gramme of hydrogen or 31½ grammes of copper, it would deposit 700,000 grammes of clay." All other naturally occurring clays are probably alluvial deposits of china clay, but they are contaminated with various other materials, with which the suspended clay has come in contact in its flow to the valleys. The principal constituent of

coloured clays is oxide of iron, which to a large extent determines the colour of the clay. Admixed sand or silica is another important constituent of coloured clays. Sandy clays are generally called loams. Clays containing a large percentage of chalk (calcium carbonate) are known as marls, the chalk being in some cases as high as 45 per cent., whereas the oxide of iron may be anything up to about 10 per cent. The composition of the clay found in any particular district will determine its technical value for use in the arts, and it is perhaps not surprising that the industries thrive best where the natural product requires least treatment for use in any given process. Staffordshire is famous for its *Blue Bricks*, which are very hard, tough (compressive strength about 600 tons per square foot), and non-absorbent, the percentage gain in weight after soaking a good Staffordshire blue brick in water for twenty-four hours seldom exceeding 1 per cent.; in fact, the Post Office Specification fixes the maximum absorption allowed at 2 per cent. The clays used in these bricks would have approximately the following composition :—

Silica	64 per cent.
Alumina	20 ,,
Oxide of iron	10 ,,
Moisture	6 ,,

and it is the presence of the oxide of iron and the high temperature to which the brick is subjected in the burning process that produces the blue colour. If the brick is underburnt the blue colour does not go right through the brick, the middle of the brick then being reddish blue. *Red Wire Cut Bricks*, which are largely used by the Post Office in the construction of jointing pits and manholes, are usually made from a brick clay which requires little or no admixture of other materials in the course of manufacture. The brick works are erected as near to the clay pits as circumstances allow, and with the exception of grinding and sifting and subsequently moistening, the clay, especially in Leicestershire, requires very little manipulation before being put into the brick-making machine. The clay is forced through a rectangular die, and the long rectangular prism ($9'' \times 4\frac{1}{2}''$ section) which results is subsequently cut through by means of a wire frame into the required lengths. The bricks are then dried and subsequently burnt in kilns. Red wire cuts of good red colour are generally made from clay containing not less than 5 per cent. of oxide of iron. With regard to the proportion of oxide of iron, the following extract, which is taken from Thorpe's "Dictionary of Applied Chemistry," is of interest: "In ordinary clays, and with an oxidising atmosphere 1-2 per cent. of iron oxide produces a buff colour, 2-4 per cent. a salmon colour, and above 4 per cent. a red colour, which becomes darker as the percentage of iron increases. The presence of other impurities, however, modifies the colour produced by iron oxide considerably, and this is especially the case when a large percentage of lime or magnesia is present. Some clays

(commonly called marls) contain from 15 to 30 per cent. of lime, and although they may also contain as much as 6-8 per cent. of iron oxide, they fire to a light yellow or buff colour." In large brick works, however, the technical treatment of the local clay is soon determined by practical means, the brickmaker being more concerned with the quality of the final product than with its chemical composition. The waste bricks, tiles, etc., when ground finely enable the brickmaker to improve the quality of his ware when necessary by mixing a proportion of this with the clay, as the second firing which the ground waste or grog receives tends to improve and deepen the colour of the ware. The grog also is of value in reducing the apparent shrinkage of the clay in the drying stage. When red brick is ground fine and mixed with water and brushed on to the surface of chimney-pots and other ornamental pottery in the clay stage, it imparts a very smooth and even colour to the fired surface. A good red wire cut brick should be regular in shape, with sharp clean edges or arrises, of a uniform deep red colour all through, and a good metallic sound should be given when two bricks are knocked together. For underground jointing-pit work, especially in damp situations, it is important that the bricks shall not be too porous, and for Post Office requirements it is stipulated that bricks shall not absorb more than 10 per cent. of their weight when submerged in water for twenty-four hours. Before submerging in water the brick should be dried at 212° F. until it ceases to lose weight. Wire-cut bricks are, of course, not provided with frogs or grooves, but the wire always removes from the cut surfaces sufficient of the inequalities in the clay to provide a sufficient key for the mortar. When tested in compression a good red wire-cut brick will withstand about 200 tons per square foot, but compression tests are very difficult to carry out, as it is almost impossible to ensure that the load will be evenly distributed over the surface. For this reason, although the test is applied, no figure as a rule is specified owing to the variability of the test results. Red wire-cut bricks obtained from the same source are remarkably uniform in quality, which perhaps is not surprising seeing that the clay is generally found in large beds of uniform quality, and that the manufacturing processes are simple and uniform. Some authorities, however, prefer to have bricks provided with frogs, and as an alternative to wire-cuts when these cannot be obtained, the Post Office Specifications allow the use of pressed red bricks, stipulating, however, the same requirements as regards absorption of water as for wire-cuts. For ordinary building purposes a very low percentage of absorption is not favoured by some authorities, as it is stated that the mortar holds the brick better, especially in the case of sills, copings, etc., when the brick is of a slightly more open or absorptive texture. For a description of the method of burning bricks in clamps and the treatment of London clay, the reader is referred to the ordinary standard works on modern brick-making, as bricks made by this process are seldom used for telephone purposes.

Ducts.—When an ordinary brick clay is used in the manufacture of ducts, it is generally fired to a good buff colour all through the thickness of the wall, the inside surface of the duct being glazed. Glazed ware of this kind is termed earthenware by some authorities. The clay, after being ground and sifted, is forced from a pugmill through a shaped die and received on a travelling platform, which travels the exact length the duct is required to be. The upper end is then cut through with a wire and the two ends trimmed by hand. Sometimes a mould fitted to the platform is used to shape the lower end. Fig. 48 is a drawing of a duct which has been largely employed

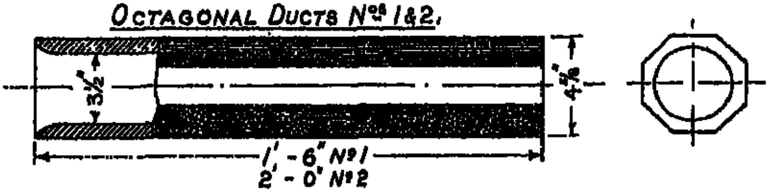


Fig. 48.

in the underground scheme of telephoning London. The duct, after being trimmed to template, is carefully and slowly dried. If the duct dries more quickly on one side than the other strains are set up in the clay, producing curved ducts. After drying the ducts are close stacked in a kiln and fired. Towards the end of the firing process a few shovelfuls of ordinary common salt (sodium chloride) are thrown on the fire. The salt volatilises and passes into the kiln, combining with the hot ware to form a glaze or glass on the interior of the ducts, the close stacking preventing the fumes from glazing the exterior surface. The following paragraphs are extracted from the Post Office Specification for earthenware ducts :—

"The following table gives the maximum and the minimum dimensions that will be allowed :—

	Maximum Ins.	Minimum Ins.
Length 18-in. ducts	$18\frac{1}{2}$	18
" 24- " "	$24\frac{1}{2}$	24
Width across flats	$4\frac{5}{8}$	$4\frac{1}{2}$
Internal diameter	$3\frac{1}{2}$	3[illegible]
Thickness		$\frac{1}{2}$

"Care should be taken to prevent the ducts from becoming curved during the drying process. Those which show a greater dip than $\frac{1}{4}$ inch for the 24-inch ducts, and $\frac{5}{32}$ inch for the 18-inch ducts, cannot be accepted. Ducts curved in more than one direction will be rejected. To be clean glazed inside and free from all projections

such as blisters, droppers, and ironstone. The ducts need not be glazed on the outside. The ducts to show no bulging at the ends, and the opposite flat sides to be parallel throughout. A gauging disc $3\frac{5}{16}$ inches diameter will be passed through each duct."

Every duct should be examined to see that the interior is free from projections that would be likely to injure lead-covered cable.

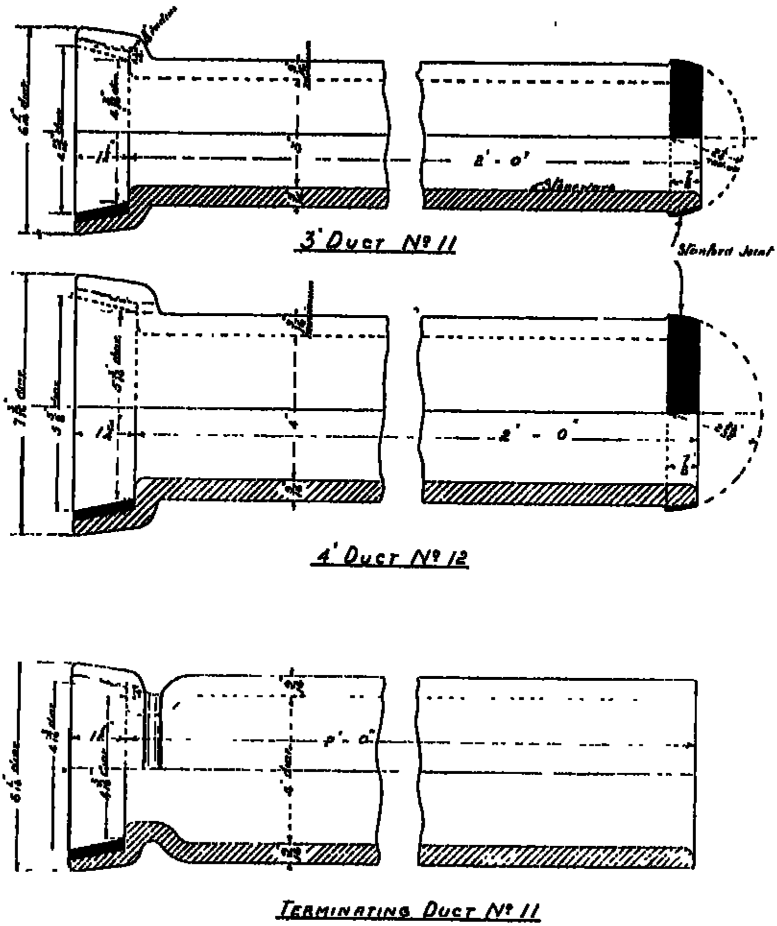


FIG. 49.

Occasionally "droppers," which are pieces of the glaze that accumulates on the roof of the kiln, fall on the ducts during the firing, and these have to be removed by rasping. The slightly rough place left after removal of the dropper will not cause any trouble if the duct is laid so that the roughness is on the top of the duct. It is usual to mark each approved duct with a dab of paint or an arrow

and certain letters, and if these marks are put on that side of the duct which will be at the top when laid, the rough places above referred to are taken care of. Similarly, where curved ducts are approved the mark should be on that side which will ensure the plane of the curve lying horizontal and not vertical. Curved ducts are given a green mark and others a red mark. The working gauging disc is 20 mils larger than the specified disc diameter ($3\frac{5}{16}$ inches), to allow for wear, but gauging discs of the exact diameter are provided, and only those ducts are rejected which will not allow the latter to be passed through. The gauging disc of exact diameter has a bevelled edge for ease in identification. The ends of the ducts should be well rounded off, as shown in Fig. 48, so that no ridge likely to injure lead-covered cable will be formed when the ducts are laid. It has not been the practice hitherto to specify any tests for this type of duct as regards absorption of water or compressive strength.

Self-aligning ducts have of recent years been used in large quantities. The dimensions and shape of the single-way ducts are shown in Fig. 49. The spigot and socket linings are made of Stanford's composition, which is capable of withstanding a temperature of 140° F. without losing its hardness. It is stipulated that the salt glaze shall cover the interior and also the exterior surface of the ducts, which will remain exposed after jointing. The linings should adhere firmly to the ducts, and be cast so that when the ducts are jointed they centre correctly and are in true alignment. The surface of the spigot lining should be part of a sphere, and that of the socket lining part of a cone, as shown in Fig. 49. The shape and surface of the linings should allow of a satisfactory watertight joint being made by means of a thin luting of a suitable compound. The inside edges of both ends of the ducts should be rounded off as shown in the figure.

The following table gives the principal dimensions of the ducts :—

Duct Number.	Diameter.			Minimum Thickness of Material.	Standard Length, excluding Socket.	Length of Socket.
	Standard.	Minimum.	Maximum.			
	ins.	ins.	ins.	in.	ft.	ins.
11	3	$2\frac{7}{8}$	$3\frac{1}{8}$	$\frac{9}{16}$	2	$1\frac{1}{8}$
12	4	$3\frac{7}{8}$	$4\frac{1}{8}$	$\frac{9}{16}$	2	$1\frac{3}{4}$

Specified Tests.—These ducts should not have a greater deviation from straightness than $\frac{3}{16}$ inch on a 2-feet length when measured by straight-edge on the inside of the arc.

A mandril 2 feet long and $\frac{1}{4}$ inch less in diameter than the standard bore of the duct is passed through each duct. The bore may also be tested by passing a gauging disc $\frac{3}{16}$ inch less than the standard diameter of the duct.

The absorption is tested on samples taken from the body of the duct at least 6 inches from either end, and including the whole thickness of the duct and two glazed surfaces. Each sample is dried at a temperature of 150° C. until no variation in weight can be noted. It is then submerged in cold water, the temperature of which is subsequently raised to boiling-point, and maintained at that temperature for one hour. The sample is removed from the water when cool, carefully wiped with a dry cloth and re-weighed. The increase in weight of each sample by absorption of water must not exceed 5 per cent.

The ducts should be capable of withstanding a minimum distributed load of 30 cwt. applied at right angles to the axis between two wood blocks, the lower block 24 inches long and the upper block 12 inches, felt washers being placed between the blocks and the duct.

The same method of marking curved ducts and those containing rough places, as described on page 136, is applied to these ducts. It is usual to use the $3\frac{9}{16}$-inch gauge (working size, 20 mils larger) on each duct, and to apply the mandril to a percentage only.

Multiple ducts having two, three, four, six, or nine circular ways $3\frac{1}{4}$ inches diameter of the self-aligning type are also largely used. The tests and requirements are similar to those applying to single-way ducts, except that the former are required to withstand without cracking a distributed load of 20 tons per foot run. With multiple-way ducts it is very important—especially with the three-way—to check that the alignment is correct, and one or two batches should be tested every day during examination at the contractor's works to ascertain whether the ducts when pushed home joint themselves in true alignment. This test may be made by jointing twenty ducts and then drawing an iron mandrel $9\frac{1}{2}'' \times 3\frac{1}{4}''$ through each way of the multiple duct. Multiple ducts bear a black paint mark on that face which will be the bottom face when the ducts are laid, and it is important that the ducts should be laid in this position if satisfactory alignment is to be obtained.

The following is a summary of the mandrels and gauging discs required for each kind of duct :—

	Working Mandrels.	"Exact" Mandrels.	Mandrels for Alignment Test.	Gauging Disc.
	ft. ins.	ft. ins.	ins.	ins.
Multiple ducts . .	$2 \times 3\frac{9}{32}$	$2 \times 3\frac{7}{32}$	$9\frac{1}{2} \times 3\frac{1}{4}$	
Ducts No. 11 . .	$2 \times 2\frac{31}{32}$	$2 \times 2\frac{3}{4}$	$9\frac{1}{2} \times 2\frac{3}{4}$	$2\frac{13}{16}$ diam.
Ducts No. 12 . .	$2 \times 3\frac{21}{32}$	$2 \times 3\frac{5}{8}$	$9\frac{1}{2} \times 3\frac{5}{8}$	$3\frac{13}{16}$ diam.

Stoneware Battery Jars.—Where clay has to be worked on the potter's wheel it is usually prepared by a washing process to eliminate all large and sharp particles. It is generally suspended in water, stirred vigorously, and then left to settle. The coarsest grains are

the first to sink, then the medium-sized, but the finest particles remain for a long time in suspension, and do not settle for several hours or even days. The slip or fine clay in suspension in water is run into special baths and allowed to settle. The water is then run off and the clay allowed to dry partially, when it is ready for the potter. Washed clay which fires to a coloured opaque body is usually termed stoneware, although the colour may be only slightly yellowish, greyish, or bluish. The battery jars used by the Post Office are made of a high-grade washed clay that fires to a bluish-grey body, and they are glazed inside and outside with common salt. The jars are placed upside down in the kiln, and consequently the exterior which comes in direct contact with the heat of the furnace is a dark brown colour, whereas the interior, which is partly screened from the direct heat, is a light coloured blue-grey. The standard dimensions of the jars are given in the following table :—

	2-Pint Jars.	3-Pint Jars.
External depth . . .	6¾ inches.	6¾ inches.
Internal " . . .	6¼ "	6⅛ "
External diameter . .	5 "	6⅝ "
Internal " . . .	4½ "	6 "
Approximate weight . .	2½ lbs.	3¾ lbs.

The jars should be cylindrical and stand flat and vertical when placed on a level surface.

Test.—The electrical resistance of each jar is determined in the following manner, viz., the jar is filled with water to within 2 inches of the top, placed in water to the same level, and allowed to soak for twenty-four hours. After the tops of the jars have been thoroughly dried—usually by a hot plate or gas jet—the jars, whilst still in the water, are tested electrically at a pressure of 100 volts. Jars giving an electrical resistance of less than 10,000 megohms are rejected. This test is a very severe one, and only stoneware which is thoroughly vitrified will comply with the specified requirements. Stoneware sometimes develops internal strains in the firing process, and stunts or cracks after being brought into use, and it is important, therefore, to ensure that battery jars will be free from this defect, or serious electrical troubles may result. A hydraulic pressure test of 20 lbs. per square inch will generally break a faulty jar, whilst a good jar is unaffected, but it is somewhat expensive to apply tests of this kind, and the alternative is to obtain supplies from a manufacturer whose products are known to be free from this defect. This test is not specified by the Post Office.

Telegraph (porcelain) Insulators are made of first grade, carefully selected materials, of which china clay is one of the principal, the others consisting of ingredients that give to the porcelain a high degree of toughness and facilitate the vitrification. The materials are thoroughly ground and sifted, and the slip is freed from all magnetic particles by means of banks of permanent magnets, past which the slip is caused to flow. The clay is removed from the slip

by the aid of filter presses, and is subsequently forced from a pugmill through a rectangular die, and emerges as a long rectangular prism. This is cut up into pieces of suitable size for the particular insulator required, and is then " thrown " on the potter's wheel to the approximate solid shape desired. After drying slightly the solid shape is put into a lathe and turned and screwed to the shape shown in Fig. 50. The insulator is then dried for several days, during which time considerable shrinkage takes place, and, as would be expected, the vertical shrinkage, owing to the action of gravity, is greater than that taking place in a horizontal plane. The insulator is carefully examined at this stage to detect any minor defects, especially small cracks. The insulator is then fired in a kiln at a very high temperature, the body being thoroughly vitrified. It is again examined for defects, and then finally dipped in a frit or glazing liquid and fired in a glost furnace at a moderately high temperature. Frits containing lead compounds give the best glaze, but leadless frits have of late years been obtained that seem likely to compare favourably with the lead frits. Exceptional precautions have to be taken to protect the workpeople from inhaling the lead compounds where lead frits are used, but the insulator trade is singularly free from cases of lead poisoning, as the arrangements made by the manufacturers for protecting the workpeople are practically perfect.

The finished insulators are gauged with the " Tell Tale," " Plug," and " Screw " gauges shown in Fig. 50. The screw gauge is not a Whitworth thread, although it is somewhat similar, only differing in the angle of the thread and one or two minor details. The gauge is made by Messrs. Bullers, Limited, of Tipton, Staffordshire. The insulator will not screw on satisfactorily to a Whitworth thread, owing to the differences referred to. The principal and practically only defect occasionally found in these insulators is a very fine crack in the top or in the sheds, which frequently cannot be seen, but can be detected by soaking the insulator in water—say for twelve hours—and testing it electrically at a pressure of about 100 volts. It is important to eliminate insulators containing this defect, because it will cause out of balance trouble on a telephone loop, and there would be great difficulty in locating the cause of the trouble if the insulator were brought into use. The body of the insulator, when broken, should be entirely free from porosity, which can be roughly determined by making a red ink mark on the fractured surface, leaving it a few minutes, and wiping with a damp cloth. There will be no ink stain left if the ware is thoroughly vitrified. When subjected to an alternating current pressure test, the body is not punctured, the breakdown occurring as a flash over from the wire in the groove to the steel supporting spindle at about 40,000 volts. In practice the only test applied is that for detecting cracks in the insulators. The body of the insulator is rightly described as porcelain, as when fired in thin plates the material is translucent, which is one of the principal characteristics of porcelain, but, of course, this property cannot be detected in the thick walls of the

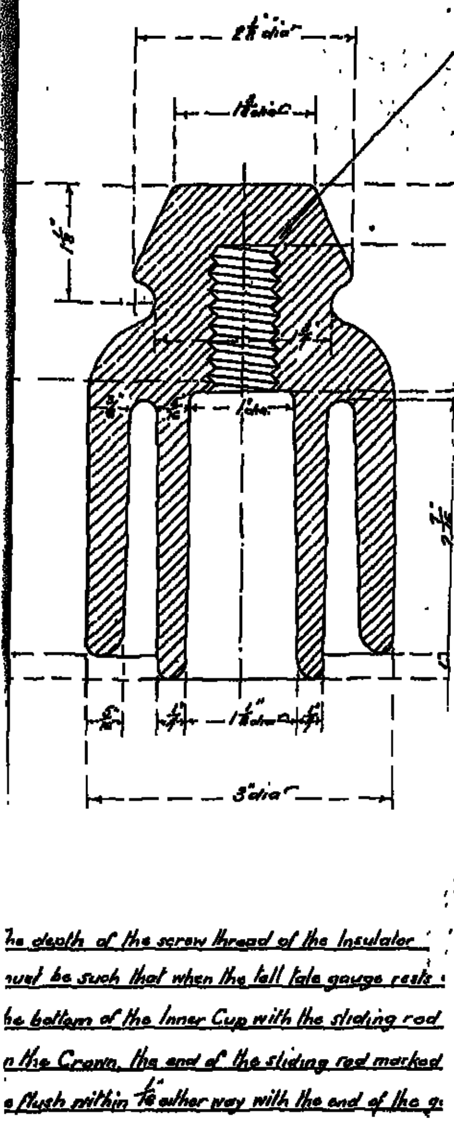


Fig. 50.—Telegraph insulators.

insulator. Most of the brown insulators are made of stoneware, similar to that used for battery jars, and they are glazed by the same process. They are gauged and tested in the same way as porcelain insulators.

Portland Cement.—Probably no material of construction has received so much successful scientific attention in the last twenty years as Portland cement, and the result is that not only is the tensile strength of the cement more than double that frequently met with in the old days, but what is of much more imporance, the uniformity in quality and general soundness of the material have been enormously improved, and the cement now produced is quite reliable. The wet process of manufacture followed by the Associated Portland Cement Manufacturers at Gravesend may be briefly and popularly described as follows. The raw materials are chalk (calcium carbonate) and clay. The latter is obtained from the banks of the Medway, and the chalk from the quarries in the district. The clay and chalk in the correct proportions to produce the right result are tipped from waggons into a bank of washmills, where they are mixed with water and ground to a very fine state of subdivision by means of rotating paddles and round pebbles. There are six of these mills through which the slip or slurry passes in succession, the last two mills being provided with fine screens through which practically nothing can pass that would be left on a sieve of 32,400 meshes to the square inch. The slurry is then pumped into huge mixing tanks and its chemical composition determined by analysis. If the composition is not exact it can be corrected by altering the proportion of chalk to clay passing through the washmills. When the composition is found to be correct and the slurry thoroughly homogeneous, it is pumped to a rotary kiln. The kiln consists of a steel cylinder about 100 feet long and 7 or 8 feet in diameter, lined with fire-resisting material. It is mounted on friction rollers, the front end being 6 or 7 feet higher than the other end, i.e. it is inclined to the horizontal, so that the slurry entering at the front end is carried down slowly by gravity as the kiln rotates. The kiln is fired by means of pulverised coal or slack blown in at the lower end. The slurry in its passage down the kiln is acted upon by the hot gases, losing first the water, then the carbon dioxide of the chalk, and finally being roasted until the resulting lime and clay combine into silicates and aluminates of calcium in the form of small pieces, technically termed clinker. The temperature in the middle of the rotary kiln is about 2600° F., and the issuing clinker at the bottom end is at a temperature of about 2000° F. The hot clinker falls into a second rotary cylinder, which acts as a cooler for the clinker and also as a heater of the blast for the kiln, since the clinker gives up its heat to the incoming blast. The temperatures of the cooler and the kiln are under scientific regulation, as the quality of the product of course depends entirely upon the heat treatment at this stage. The gases issuing from the kiln at the higher end enter a very tall chimney in a relatively cool condition, the temperature being

probably not more than 450° F. The approximate chemical composition of the clinker is given by Mr. H. K. G. Bamber, F.C.S.,* as follows :—

Soluble silica	21·98 per cent.
Insoluble residue	0·24 ,,
Oxide of iron and alumina . . .	10·20 ,,
Lime	64·96 ,,

which complies with the test for chemical composition in the Engineering Standards Committee's Specification, which requires that the ratio of lime (after deduction of the proportion necessary to combine with the sulphuric anhydride present) to silica and alumina $\left(\frac{CaO}{SiO_2 + Al_2O_3}\right)$, calculated in chemical equivalents, shall not be greater than 2·85 or less than 2·0, the insoluble residue shall not exceed 1·5 per cent., magnesia not more than 3 per cent., and the total sulphur, calculated as SO_3, not more than 2·75 per cent. The total loss on ignition should not exceed 3 per cent. The initial grinding of the clinker is the next operation, and this is done in ball mills consisting of steel rotary cylinders, lined with a series of sieves and plates, and partly filled with steel balls, the whole arranged so that during rotation these balls fall off the plates on to the cement at the bottom. The clinker is mixed with these balls, and the rubbing and pounding it receives reduces the clinker to a fine powder, which finds its way eventually through the fine meshed surrounding sieve. The fine powder is passed on immediately to the tube mill for final grinding. This mill is also a steel rotary cylinder, but is charged with round pebbles (flints) which grind the cement before it issues at the far end to such a degree of fineness that about 95 per cent. will pass through a sieve having 32,400 holes to the square inch, i.e. 180 × 180 meshes. The Standards Committee's Specification limits the residue on this sieve to 14 per cent. as a maximum when 100 grammes (4 ounces approximately) have been continuously sifted for fifteen minutes, and then not more than 1 per cent. residue on a sieve having 5776 meshes or holes per square inch, i.e. 76 × 76, the two siftings being taken consecutively in the order given. It is pointed out by Mr. Bamber that the clinker before grinding has no cementitious value whatever, and can be stored without injury in damp places for long periods. When ground to this high degree of fineness, however, it not only attains its characteristic cementitious properties, but sets very rapidly, and it is necessary for commercial purposes to retard its setting time. This retarding of the setting time may be accomplished by adding a small percentage of gypsum ($CaSO_4$, $2H_2O$), or by causing the cement during the final grinding to come periodically in contact with moist air. The former method is not viewed with favour by some engineers,

* Lecture on Portland Cement delivered in December, 1907, before the Glasgow Association of the Institution of Civil Engineers.

and the Standards Committee's Specification in limiting the sulphur as SO_3 to 2·75 per cent. provides for the possible addition of gypsum, and consequently sulphur, for this purpose. The latter method is accomplished by injecting steam into the tube mill during the final grinding process, and is free from any possible objection, providing the total loss on ignition does not exceed 3 per cent. The setting time can be regulated by the manufacturers within very wide limits, and the Standards Committee's Specification covers two different grades, viz. :—

Specially Quick.—Initial setting time not less than two minutes.
Final setting time not more than thirty minutes.

Unless a specially quick setting cement is required, the
Initial setting time is not less than twenty minutes, and the
Final setting time not more than ten hours.

For Post Office work cement having the latter setting time is generally used. The initial and final setting times are determined by gauging a pat of neat cement, putting it into a ring mould (approximately 3 inches diameter and 1½ inches high), which rests on a glass plate, and trying it periodically with a vicat needle weighing approximately 10½ ounces, and having a point 1 millimetre square. The needle is gently applied to the surface of the pat, and when it fails to pierce the cement completely the initial set is regarded as having taken place. The time is reckoned from the instant the cement was put in the mould. The final set is regarded as taking place when a cuplike attachment, fitted ½ mm. from the end of the needle, fails to make an impression when the needle is applied gently to the surface of the cement.

The tensile strength of Portland cement is determined by gauging six briquettes of neat cement, keeping them in a damp atmosphere (wet cloth usually) for twenty-four hours, and afterwards removing them from the moulds and submerging in clean fresh water (temperature from 58° to 64° F.) for six days. The average breaking stress of the six briquettes seven days after gauging should not be less than 450 lbs. per square inch. Generally speaking, the more finely ground the cement is the higher is the tensile strength, and it is mainly on account of the finer grinding that modern cement has twice or sometimes three times the strength of cement procurable thirty years ago. The specific gravity of new cement, that is, cement that has not been ground more than a few days, is about 3·15, but cement which has been ground earlier than this, say three or four weeks, is somewhat lower, but the 1920 edition of the Standards Committee's Specification does not stipulate any limit for specific gravity. The test for soundness is made in a Le Chatelier apparatus, which consists of a split ring mould, to the edges of which are attached two small rods or pointers 6½ inches long. The neat cement is put into the mould and a glass plate is placed on the top, one having also been used as a support for the mould. A small weight is placed on the top glass plate, and the whole is then put into clean

water (58° to 64° F.) and left there for twenty-four hours. The distance between the ends of the rods is then measured and the mould replaced in the water, which is heated to boiling-point in twenty-five to thirty minutes, and kept boiling for six hours. The mould is then removed from the water, allowed to cool, and the distance between the ends of the rods again measured. The difference must not exceed 10 millimetres in ordinary circumstances. It should be mentioned that before testing for tensile strength and soundness, the dry cement should be spread out for a depth of 3 inches for twenty-four hours in a room at a temperature of from 58° to 64° F. All cement used by the Post Office is purchased to the British Engineering Standards Association's Specification, and for full details of the tests the reader is referred to the Standard Specification, the foregoing description being abridged in many details. The specification can be obtained from the British Engineering Standards Association, 28 Victoria Street, S.W. 1, price 1s. 2d. post free.

CHAPTER VIII

PAINT AND CREOSOTE

In addition to its decorative effect, paint is required to have a preservative effect on the article painted. To secure the latter result it is important that the coating of paint shall be continuous and highly resistant to atmospheric action. For ordinary engineering purposes oil paints are used, and the oils are perhaps the principal preservative agents. Paints usually consist of a base such as white lead, a pigment to produce the desired colour, raw and boiled linseed oil, and turpentine or other thinner. When linseed oil is exposed in a thin layer to the air it combines with oxygen from the air, and dries during the process to an elastic film. Boiled linseed oil oxidises more rapidly under these conditions than raw linseed oil, but if used to excess in paint it is likely to contract considerably and to develop a network of fine cracks. For this reason it is usual to employ both raw and boiled linseed oil in paints. The turpentine acts as a solvent and thinner of the oils, and thins the paint sufficiently to enable it to be applied in thin coats. The bulk of the turpentine evaporates during the drying process, and the small quantity that remains in the paint after drying is probably present as an oxidation product or as rosin. If a large proportion of turpentine is used in paint, the paint dries with a dull matt finish. An excess of boiled oil produces a glossy surface, but there is a danger, as previously mentioned, that cracks will develop. Where a glossy finish is desired and a very durable paint is needed, this can be obtained by adding to an ordinary paint a small quantity of good oil varnish. The quality of a varnish depends very largely upon the quality of the resin with which it is made, provided that the manufacturing process is equally satisfactory in all cases. Varnish is made by melting the resin, mixing it with boiled hot linseed oil, boiling the mixture, and thinning with turpentine. Post Office supplies of paint are obtained under competitive tenders to a definite specification, and in judging the merits of the numerous samples submitted with the tenders, it is necessary to apply a series of comparative tests. Wherever practicable white lead is used as the base, as paint made with genuine white lead works more freely and satisfactorily from the brush than any other base. The hands should be thoroughly washed after using lead paints or any other compounds containing lead, because lead poisoning may be set up if the lead

gets under the finger nails or into an open cut in the flesh. White lead is manufactured under various patent processes, a description of many of which will be found in Hurst's "Painters' Colours, Oils, and Varnishes," published by Griffin & Company. The oldest process is the Dutch process, and is still largely used. It consists of acting on metallic lead with acetic acid vapour in the presence of carbon dioxide. The weak acid is put into an earthenware pot, and a coiled sheet of lead is supported just above the acid by a ledge in the pot. Under the pot is placed a layer of ashes, and on the ashes a layer of spent tan bark or other substance which will with moderate heat or fermentation yield carbon dioxide. The heat vaporises the acid and the fumes corrode the lead, forming basic lead acetate, which in the presence of carbon dioxide decomposes, with the formation of white lead or basic lead carbonate ($2PbCO_3, Pb(OH)_2$). In this cycle of reactions, therefore, the acetic acid acts as a carrier, a comparatively small quantity being able to convert an indefinite amount of lead into white lead. The white lead is subsequently ground to a fine powder. The Post Office Specification for white lead (genuine) in oil stipulates that it shall consist of basic carbonate of lead containing not less than 84 per cent. of lead oxide and not more than 0·5 per cent. of impurities, the white lead being ground in from 7 to 10 per cent. of *refined* linseed oil. The following paragraphs are extracted from the Post Office Specifications for paint stores.

Lead Colour Paint (Mixed)

The materials to be of the best quality and to include not less than 70 per cent. of genuine white lead as above, and 2 per cent. of vegetable black (carbon). The remainder to consist of driers, boiled linseed oil, raw linseed oil, and turpentine in such proportions as will ensure the paint drying satisfactorily within twenty-four hours when used inside. The paint to be thoroughly ground and mixed ready for use.

Stone-colour Paint (Mixed)

The materials to be of the best quality and to include not less than 70 per cent. of genuine white lead as above, tinted with ochre and burnt umber to match the Department's pattern. The remainder to consist of driers, boiled linseed oil, raw linseed oil, and turpentine in such proportions as will ensure the paint drying satisfactorily within twenty-four hours when used inside. The paint to be thoroughly ground and mixed ready for use.

White Paint (Mixed)

The materials to be of the best quality and to include not less than 70 per cent. of genuine white lead as above, tinted with ultramarine, to match the Department's pattern. The remainder to consist of driers, boiled linseed oil, raw linseed oil, and turpentine in

such proportions as will ensure the paint drying satisfactorily within twenty-four hours when used inside. The paint to be thoroughly ground and mixed ready for use.

Red Oxide Ground in Oil

The pigment to consist of genuine red oxide of iron (ferric oxide) ground in from 7 to 10 per cent. of refined linseed oil, and to contain not less than 70 per cent. of ferric oxide mixed with sufficient calcium carbonate, calcium sulphate, or barytes to produce the tint referred to below.

Red Oxide Paint (Mixed)

The mixed paint to contain not less than 60 per cent. of red oxide ground in oil as described above. The remainder to consist of boiled linseed oil, raw linseed oil, driers, and turpentine in such proportions as will ensure the paint drying satisfactorily within twenty-four hours when used inside. The paint to be thoroughly ground and mixed ready for use, and to be in reasonable agreement with the Department's pattern as regards tint.

Brunswick Green

To be prepared with genuine Brunswick green to the Department's tint, and to be mixed with genuine turpentine and oil and sufficient driers to dry within twenty-four hours.

Chocolate-colour Oxide Ground in Oil

The pigment to consist of approximately 70 per cent. chocolate-colour oxide of iron, ground in from 7 to 10 per cent. linseed oil and mixed with sufficient calcium carbonate, calcium sulphate, or barytes to produce the tint referred to below.

Chocolate Paint (Mixed)

The mixed paint to contain approximately 60 per cent. of chocolate-colour oxide ground in oil as described above. The remainder to consist of boiled linseed oil, raw linseed oil, turpentine, and driers in such proportions as will ensure the paint drying satisfactorily within twenty-four hours when used inside.

Black Paint (Mixed)

To be made with the higher grade fine lamp black, genuine linseed oil, and turpentine, with sufficient driers to ensure it drying to a hard glossy coat in twenty-four hours when used inside.

Note.—The mixed paint to be of such a consistency as to be suitable for immediate use. The turpentine referred to in this specification to consist wholly of genuine turpentine, as defined in the Department's specification for turpentine.

The specification for turpentine is as follows: "The turpentine to have a specific gravity of not less than 0·860 at 60° F., a flash point of not less than 90° F., and to satisfy the following distilling test, viz., 100 cubic centimetres of the turpentine will be gently heated in a Wurtz flask attached to a Liebig's condenser, when not less than 90 cubic centimetres shall distil between the temperatures of 156° and 175° Centigrade."

In judging the merits of a mixed paint it is necessary to take into account its covering power and also its hiding power or body. The grinding process is expensive, and in a measure the amount of grinding determines the cost of producing the paint. The best classes of paints are very finely and evenly ground, with the result that they cover weight for weight a much greater area than a paint that has not been so thoroughly ground, and further, the fine grinding gives a better and more uniform appearance, while there is no diminution in hiding-power or body. To determine the covering power of a paint it is essential that uniform methods of procedure should be followed if comparable results are to be obtained. The procedure followed in the Post Office is as follows: Yellow deal boards are given one good coat of red lead priming, and are allowed to dry. The red lead priming should contain a fair proportion of white lead, as the latter fills up the pores of the wood more satisfactorily than red lead, and if specially made for the purpose, the following composition will be found convenient: 1½ lbs. white lead in oil, 3 ounces red lead, 1 ounce driers, 1 gill of turpentine. After the priming coat is thoroughly dry the surface is rubbed down with glass paper. Boards with good surfaces should be selected for the purpose, so that no stopping with putty should be necessary. The paint to be tested is then thoroughly stirred until it is homogeneous. The paint brush—an ordinary sash tool—is well worked in the paint and then transferred to a glass beaker, together with a sufficient quantity of the paint for the test. Beaker, brush, and sample of paint are then accurately weighed, and immediately afterwards a 2 square foot surface of the primed board is given a thin coat, the painting being done by an expert painter. The beaker, brush, and paint are again weighed, and the loss of weight is taken as the amount used in the test and applied to the board. The remainder of the paint is put back into the sample tin and the latter tightly sealed. The coat of paint is allowed to dry, notes being taken of the appearance and rate of drying, and a comparison is made with the Department's pattern or other samples submitted. The covering power is expressed in square feet per lb. of paint, or the number of square feet 1 lb. of paint will cover in one coat. Where such a small surface is taken for the purposes of comparison, great accuracy in weighing and procedure are imperative if reliable results are to be obtained, and it can usually be done best in a chemical laboratory. It is obvious that where one of the ingredients is volatile when exposed to the air—the turpentine—any long exposure such as

would be required to paint a large surface should be avoided if uniform conditions and weights are to be the basis of comparison. The method described above with ordinary care gives good results. As soon as the covering power coat is properly dry, a further and thicker coat is applied to 1 square foot of the previously painted surface, and this second coat is compared with the pattern for general appearance and suitability. No weighing is done with this coat.

The following method is convenient when analysing a mixed paint containing white lead as the base.

Determination of Oil and Thinner.—Stir the sample thoroughly, then weigh out in a beaker 10 to 20 grammes. Add about 30 c.c. benzol (C_6H_6), stir well, then allow to stand in a warm place till the solids have settled. Decant the liquid carefully, and repeat the treatment with benzol three times. Finally allow the beaker to stand in a warm place till all benzol has evaporated, then cool and weigh. The loss of weight may be taken as the weight of oil and thinner.

Estimation of White Lead.—1 gramme of the dried solids obtained in the estimation of oil and thinner is dissolved in dilute nitric acid. If there is any insoluble matter present, this should be filtered off and weighed. The solution is evaporated with sulphuric acid until all nitric acid has been driven off, and is then diluted with water and allowed to stand for twenty-four hours. The precipitated lead sulphate is filtered off, dried, ignited gently, and weighed. The precipitate should be completely soluble in a dilute hot solution of sodium thiosulphate (absence of barium sulphate). The weight of lead sulphate found is calculated to basic lead carbonate and expressed as a percentage of the total dried solids. The carbon dioxide is estimated by taking about 2 grammes of the dried solids, treating them with moderately dilute nitric acid, and absorbing the carbon dioxide in a soda-lime tube. The weight of carbon dioxide found is calculated to basic lead carbonate and expressed as a percentage of the total dried solids. This should agree approximately with the percentage previously found.

Turpentine.—To determine whether turpentine only has been used as a thinner, and not petroleum or rosin spirit, about half a pound of the paint is placed in a flask, fitted to a condenser, and steam distilled for about one hour. The distillate is poured into a separating funnel and the thinner separated into a test-tube containing a little dry calcium chloride. The thinner is then examined in an oleo-refractometer (made by Messrs. Baird & Tatlock). The refraction of turpentine in this apparatus ranges from + 6 to + 14, whereas rosin spirit gives a variable but moderate minus refraction, and petroleum spirit minus 100 to minus 140. The presence of petroleum can be confirmed by shaking up a small measured quantity of the distillate with ten times its volume of aniline (pure) in a graduated tube. The aniline dissolves the turpentine but leaves the petroleum undissolved, and this separates out after standing

some time, and its approximate quantity can be read off. If co tar spirits (benzol, etc.) are present some of the petroleum is solubl

Rosin spirit gives a reddish coloration with concentrated nitri acid, and acts more slowly and less violently than turpentine. Th ultimate action of both, however, is very violent with nitric aci and the test requires to be carried out with care.

The chemical examination of a mixed paint is a difficult operatio and requires considerable skill. The foregoing description is onl a brief outline of the process, and in practice this may have to b considerably departed from if the composition of the paint is widel different from that set forth in the Post Office Specification. Th oleo-refractometer referred to is very useful in examining oils of al kinds, especially linseed oil; in fact, the amount of boiling tha boiled linseed oil has been given can be approximately estimate from its refraction value. A full description of the apparatus ca be obtained from the makers, but is too long and not of sufficien general interest for inclusion here.

Creosote for Preserving Wood

The creosote used by the contractors to the Post Office fo creosoting poles is purchased in the districts where the poles ar treated, and the composition of the creosote varies slightly accordin to the district in which it is produced. Creosote is obtained fro coal tar during the process of distillation, and consists of severa phenolic, oily, and basic ingredients, the principal of which are pheno (carbolic acid), cresol, naphthalene, anthracene, acridine, and phenan-threne. The proportion in which these several ingredients shoul be present is not rigidly specified, and in chemically examinin creosote it is generally sufficient to distil it fractionally and ascertai the amount of distillate at certain temperatures, and to determin the percentage of phenoloids and naphthalene. The limits that ma be regarded as satisfactory can be approximately stated as follows:—

(1) Not to contain more than 2 per cent. of matter volatile at 100° C.
(2) To be completely liquid at 38° C.
(3) To leave not less than 25 per cent. or more than 35 per cent. residue when distilled up to a temperature of 316° C.
(4) To contain not less than 5 per cent. of phenol and other phenoloids (tar acids).
(5) To contain not less than 15 or more than 25 per cent. of naphthalene.

It is not desirable to insist upon a definite proportion of any particular constituent except within fairly wide limits, as this would probably have the effect of raising the price of the creosote to a prohibitive figure. The practice followed by the Post Office is to test each contractor's creosote, and if it be found to be a genuine commercial article having a reasonable proportion of the desirable

constituents, to allow it to be used for creosoting poles. Authorities differ with regard to the relative value of the constituents, but most are agreed that the tar acids or phenoloids, which have a strong antiseptic action, are desirable within limits. In creosoting telegraph poles it is found that at the pressures used the creosote penetrates the sapwood only, little or no creosote getting beyond the first one or two annual rings of the heart wood. When poles are first erected, part of the creosote settles in time at the bottom of the pole. Some old poles were chemically examined about twelve years ago, and it was found that the amount of creosote at the top of the pole was only one-seventh of the amount originally present, and that it was only slightly greater than this half-way along the pole, whereas at the ground line the quantity was one-third of that originally present. The opportunity was taken to examine the creosote extracted from these old poles, and it was found that when this creosote was subjected to distillation nothing distilled below a temperature of 320° C. It is evident, therefore, that the phenol, cresol, and the other phenoloids, and also the naphthalene, had disappeared, but the basic substances, such as acridine, were still present. It was noticed that the creosote extracted from the pole at the ground line part was more fluid than that obtained from the top, and it is possible that a trace of phenolic substance may have been present there. Naphthalene is solid at air temperatures, and takes the form of white pearly soft plates. It is volatile, and in time entirely disappears. When a pole is first creosoted, the presence of the naphthalene probably retards the downward flow of the creosote when the pole is erected, and tends to seal up the wood, its subsequent evanescence being probably spread over a number of years. Naphthalene has a characteristic tarry odour, and is sometimes used to keep moths out of clothing, but whether it repels boring insects that may attack poles is a moot point. Its presence in creosote for wood preserving is undoubtedly desirable. In chemically examining creosote it is convenient to distil it from a Wurtz flask with a side delivery tube attached to a Liebig's condenser, 100 c.c. of creosote being used for the purpose. It is advisable to screen the flask from draughts of cold air, since the final temperature is rather high. A tin-plate open-ended cylinder slotted for the side tube and fitted with a mica window, so that the flask can be seen, has proved suitable. The rate of distillation should be such that the process is completed in about twenty minutes, the distillate passing over in drops at about one second intervals. The distillate is received in a graduated cylinder and the quantity noted at 100° C. and at other convenient temperatures up to 316° C. The thermometer in the flask should be just above the level of the creosote when the heating is commenced. On completion of the distillation the distillate is transferred to a flask and warmed to liquefy the naphthalene. The warm liquid is then shaken up with about 40 c.c. of 10 per cent. caustic soda solution, which combines with the phenoloids, and the liquid containing the soda can be separated from the remainder in

a separating funnel. The residue is again warmed and treated with 30 c.c. of 10 per cent. caustic soda, and separated as before. The soda solutions are added together and placed in a graduated stoppered cylinder, dilute sulphuric acid (1 of acid 1·84 specific gravity to 2 of water) being added until the soda is neutralised and the solution is slightly acid. The phenoloids float on the liquid, and their amount can be read from the graduations.

The part of the distillate not acted upon by soda is allowed to cool and the naphthalene separates. The naphthalene is slightly soluble, and more will come out at lower temperatures if the liquid is artificially cooled, but it is usually sufficient to estimate the naphthalene at ordinary air temperatures, or, if desired, at 4° C. The creosote is pressed out of the naphthalene between four or five thicknesses of filter paper, and finally subjected to as great a pressure as can be obtained in an ordinary press. The weight of the naphthalene is expressed as a percentage of 100 grammes. The specific gravity of the creosote at 38° C. is usually about 1·01 to 1·02.

From the tests on old poles referred to above, it appears that the higher boiling fractions of the creosote are the most permanent. There is, however, another point to be taken into consideration in deciding upon what is the best composition of creosote, since if the creosote is not sufficiently fluid there is too little penetration of the creosote into the wood. The presence of the more fluid and powerful antiseptics, such as the phenoloids, is therefore desirable, provided that the proportion of phenoloids does not become excessive and render the creosote too fluid and liable to drain out of the wood. The British Engineering Standards Association have appointed a committee to investigate the properties of commercial creosotes, and to prepare a specification for creosote for wood preservative purposes.* Further information on the subject will be found in Lunge's "Coal Tar," Vol. II., together with the details of a more refined chemical examination than that given above.

* This British Standard Specification has recently been published, price 1s. 2d., and can be obtained from the Secretary, British Engineering Standards Association, 28 Victoria St., S.W. 1.

CHAPTER IX

DRY CELLS AND PRIMARY BATTERY MATERIALS

DRY cells are used by the Post Office in those places where it is inconvenient to recharge wet primary batteries, and for temporary special work where portability is the determining factor. For the most part they are only required to give intermittent service, and it is important that they shall not appreciably deteriorate when they are not being used to send a current. The tests applied to dry cells for telephonic purposes, therefore, are designed to ascertain the value of the cells under practical conditions, the output being measured by causing the cells to send a definite current for five hours per day every day except Sunday. The output test is completed when the E.M.F. of the cell falls at the end of the day's discharge to 1 volt, or the resistance rises to 3 ohms in the case of type W cells; 5 ohms in the case of type X cells, and 2 ohms in the case of types Y and Z. The voltage for the output test is measured on open circuit immediately after disconnection at the end of the day's discharge. The voltage is recorded daily, and is used for calculating the output in watt-hours. The E.M.F. of each cell on open circuit when first delivered, should be not less than 1·5 volts, and the fall in E.M.F. should not exceed the percentage shown in the following table after the cell has been shunted by a resistance of two ohms for a period of ten minutes.

Type of Cell.	Dimensions. Height Over All. Max.	Dimensions. Height Over All. Min.	Dimensions. Sectional. Max.	Dimensions. Sectional. Min.	Maximum Initial Internal Resistance.	Maximum Fall of E.M.F. after 10 minutes Application of 2-Ohm Shunt.	Current to be Taken Out during Output Test.	Minimum Output.
	ins.	ins.	ins.	ins.	ohms.	per cent.	ma.	watt-hours.
W	$5\frac{1}{2}$	$5\frac{3}{8}$	$2\frac{1}{16}$ sq.	$1\frac{15}{16}$ sq.	0·5	15	20	20
X	$4\frac{1}{2}$	$4\frac{3}{8}$	$1\frac{9}{16}$ sq.	$1\frac{7}{16}$ sq.	„	20	10	8
Y	7	$6\frac{7}{8}$	$2\frac{11}{16}$ diam.	$2\frac{9}{16}$ diam.	„	10	50	50
Z	$8\frac{1}{8}$	8	$4\frac{7}{16}$ sq.	$4\frac{3}{8}$ sq.	0·25	5	140	140

Where several types of cells are under test for output at the same time, it is convenient to bring the leads from each batch to a switch-

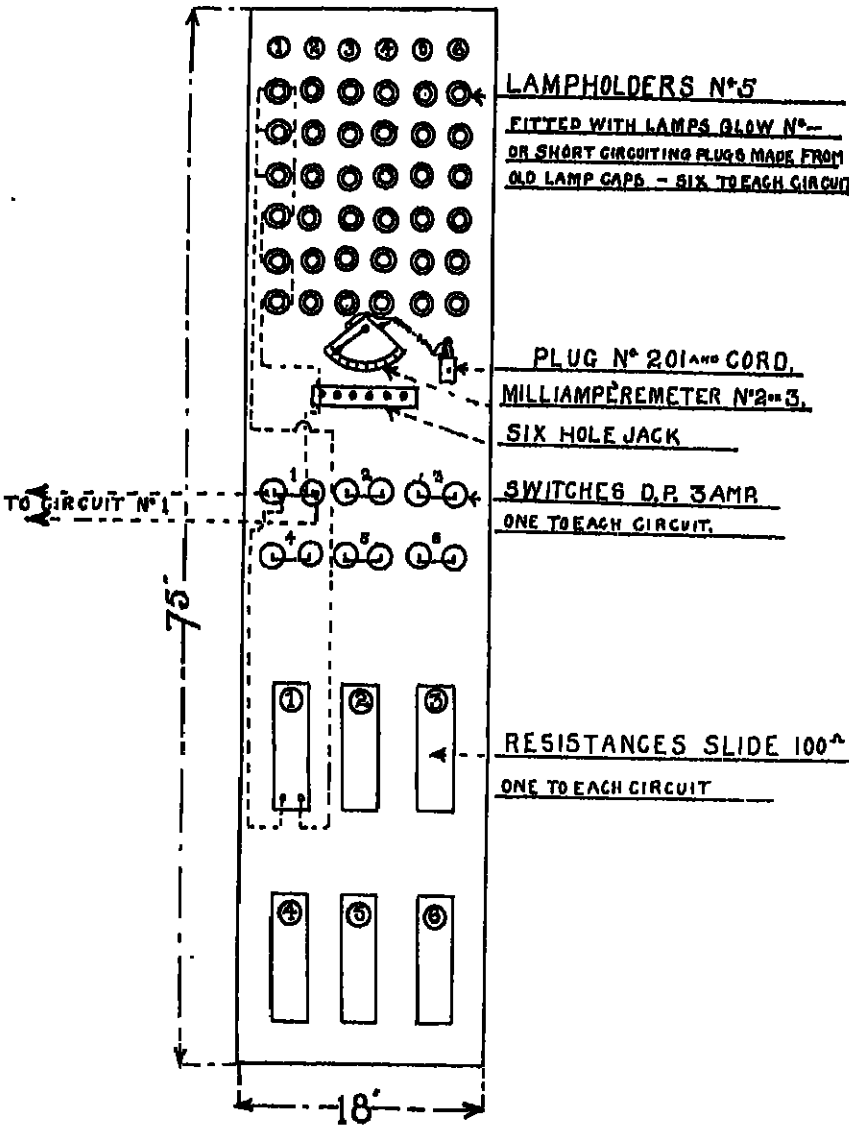


FIG. 51.—Switchboard used in testing Dry Cells.

board. Fig. 51 shows in diagrammatic form a switchboard that has proved convenient for the purpose. A first-grade milliammeter is

fitted with a two-way telephone plug (type 201), and each pair of leads from the cells under test is connected to a five-point jack (type 500A) on a strip of jacks, providing a separate jack for each batch of cells. The milliammeter can be plugged into any batch as required, and the current checked at appropriate intervals every day. The remainder of the apparatus on the switchboard consists of a double pole switch (for disconnecting the circuit at the end of the daily discharge), a rheostat, and a bank of lamps for each batch under test. The lamps are arranged three in parallel and three in series, and act as resistances, and also indicate that the current is flowing.

Where necessary old lamp caps can be used as short circuiting plugs if the lamp is not required, the appropriate short-circuit wire being fitted to the cap. The double pole switch is desirable, so that there may be no leakage at the board when the cells are not sending a current.

For testing E.M.F. and resistance of the cells a high-resistance voltmeter, arranged as shown in Fig. 52, is convenient. The test is made as follows:—

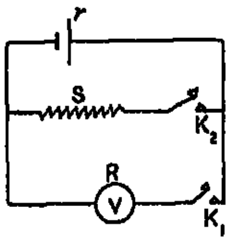


FIG. 52.

Close K_1, then $C = \dfrac{E}{R + r}$, and if R is very high, the reading on the voltmeter may be taken as the E.M.F. Otherwise $CR = V_1 = \dfrac{ER}{R + r}$ and $E = \dfrac{V_1(R + r)}{R}$. The resistance of the voltmeter must be known, and r is found by closing K_2 and reading the voltmeter V_2. In this case, if C_1 is the battery current, C_2 the current through the voltmeter, and C_3 the current through the shunt, then

$$C_1 = C_2 + C_3 = \frac{E}{r + \dfrac{SR}{S + R}}$$

$$C_2 = \frac{S}{S + R} C_1 \text{ and } V_2 = C_2 R = \frac{SR}{S + R} C_1 = \frac{SR}{(S + R)} \cdot \frac{E}{\left(r + \dfrac{SR}{S + R}\right)}$$

$$\therefore \frac{V_2}{V_1} = \frac{\dfrac{SRE}{r(S + R) + SR}}{\dfrac{ER}{R + r}} = \frac{S(R + r)}{r(S + R) + SR}.$$

Multiplying across,

$$V_1SR + V_1Sr - V_2rS - V_2rR - V_2SR = 0$$

$$SR(V_1 - V_2) = r(V_2S + V_2R - V_1S).$$

$$\therefore r = \frac{SR(V_1 - V_2)}{V_2R - S(V_1 - V_2)}$$

if V_2R is very great compared with $S(V_1 - V_2)$ this formula reduces to

$$r = \frac{S(V_1 - V_2)}{V_2}.$$

By using a high-resistance voltmeter and a suitable value for S, these conditions are obtained. About forty cells an hour can be tested separately by this method. The voltmeter should have a range of 0 to 2 volts, and be divided so that it can be read to ·0025 of a volt. The resistance may conveniently be about 1100 ohms. A voltmeter of this type is made by Messrs. Nalder Brothers. The resistance of a dry cell varies inversely, as the current which it generates, as will be seen from Fig. 53, which is the curve obtained by varying the shunt from 50 ohms in steps to 0·97 ohms, and measuring the resistance of the same cell by the above method at these different values. The actual figures obtained in the experiment were :—

V_1.	V_2.	S ohms.	r ohms.	Current Milliamperes.
1·578	1·554	50	·772	31·2
1·578	1·550	40	·723	38·8
1·578	1·545	30	·641	51·5
1·578	1·535	20	·560	77·0
1·578	1·518	10	·393	151·5
1·578	1·495	4·97	·276	301·0
1·578	1·480	3·98	·264	372·0
1·575	1·460	2·98	·235	492·0
1·575	1·430	1·97	·200	727·0
1·575	1·360	0·97	·153	1400·0

It follows, therefore, that the expression "internal resistance" of a dry cell has no meaning unless the conditions under which it is measured are stated. In measuring the internal resistance of new dry cells by the foregoing method, the Post Office practice is to use a shunt having a value of 10 ohms. The fall of E.M.F., shown in column 7, is inserted in the Post Office Specification as a rough guide to the manufacturer as to the type of cell required, and only a fractional percentage of the cells delivered is subjected to this test. The real criterion of the value of the cells is the output test.

The following paragraphs are extracted from the Post Office Specification for dry cells W, X, Y, and Z: "The zinc element of the cell to be formed into a rectangular or cylindrical case having the metal bottom and sides so connected mechanically and electrically that leakage of the contents will not take place or the electrical efficiency be impaired. The cell to be substantially designed to withstand ordinary transport and handling without damage, and with sufficient capacity to retain the contents of the cell without overflow or leakage during its full period of life.

"Each cell to be fitted with a stout cardboard cover bearing the name of the manufacturer, the letters G.P.O., and the index letter distinguishing the type of the cell. The cover to be treated with an approved insulating compound to ensure the efficient insulation of the cell from 'earth' and the cell so constructed as to be perfectly portable. The overall dimensions of each type of cell to be in accordance with the table (p. 153). The negative lead to be composed of seven strands of No. 26 S.W.G. tinned copper wires,

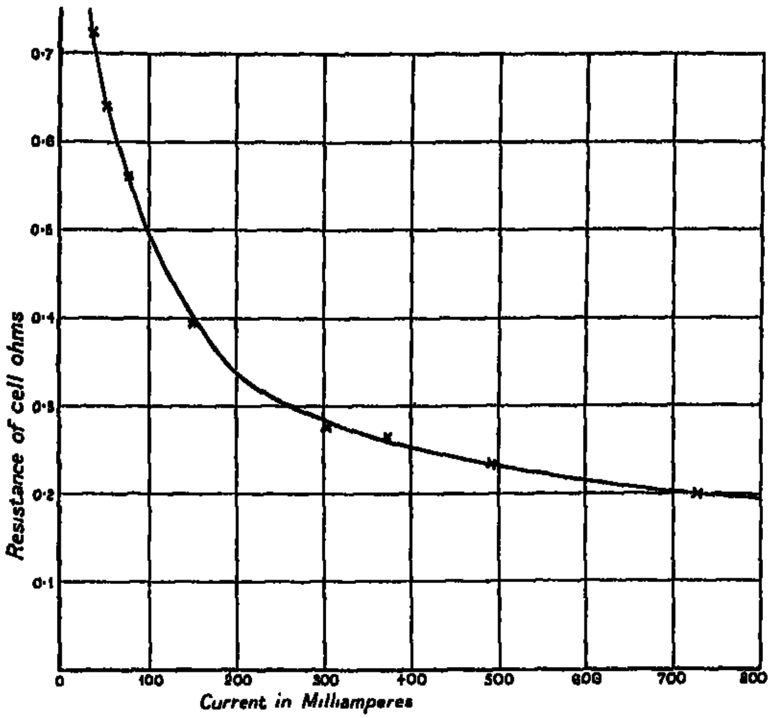


FIG. 53.—Internal Resistance of a Dry Cell.

the free end of which is to be soldered to avoid fraying. The lead to be insulated with a covering of impregnated braiding or other suitable material, the latter to be continuous with the sealing compound of the cell.

"The top of the carbon to be fitted with a brass terminal of approved pattern. The cell to be efficiently sealed and ventilated where necessary; if for the latter purpose glass tube is used, it must not project above the surface of the sealing.

"The cells to be so manufactured that after storage for a period of six months they shall show no material deterioration or local action."

A somewhat similar specification is issued for Dry Battery P, which consists of two cells permanently coupled. This battery is used in linemen's portable telephones (No. 44), and the positive and negative poles are fitted with pointed brass contacts and distinguished by the signs + and − stamped in the sealing compound. The following table gives the details :—

Type of Cell.	Dimensions.				Maximum Initial Internal Resistance. S = 20 ohms.	Maximum Fall of E.M.F. after 10 Minutes Application of 4-Ohm Shunt.	Current to be Taken Out During Test.	Minimum Output.
	Height Overall.		Sectional.					
	Max.	Min.	Max.	Min.				
	ins.	ins.	ins.	ins.	ohm.	per cent.	ma.	watt-hours.
P	$3\frac{7}{8}$	$3\frac{3}{4}$	$2\frac{7}{8} \times 1\frac{3}{8}$	$2\frac{3}{4} \times 1\frac{5}{16}$	1·0	25	10	12

Leclanché Wet Cells.—Porous pots filled with depolarising mixture and fitted with carbon rod and terminal, sealed ready for use, are purchased under the description "Cells, porous, Leclanché," in large numbers and in the sizes shown in the following table, the exciting agent and containing vessel being purchased separately :—

Type No.	Internal Diameter.	Depth Inside.	Major Axis External Maximum.	Minor Axis External Maximum.	Maximum Overall Height of Completed Porous Cell.
	ins.	ins.	ins.	ins.	ins.
0	$4\frac{1}{2}$	$6\frac{1}{2}$	—	—	9
1	$2\frac{3}{4}$	$6\frac{1}{2}$	—	—	9
2A	$1\frac{7}{8}$	5	—	—	7
2A oval	—	5	$2\frac{1}{2}$	$1\frac{3}{4}$	7

To prevent creeping the rim of each porous pot is coated for $\frac{1}{8}$ inch inside and outside with a mixture of ozokerit and pitch, or other specifically approved compound.

The depolarising mixture of manganese dioxide and carbon surrounding the carbon rod is in powder form and moistened with a dilute solution of hydrochloric acid (strength, 1 ounce of acid to a gallon of water). The initial open circuit voltage of a complete cell, consisting of rod zinc in a 15 per cent. (by weight) solution of sal ammoniac and a porous cell, should be not less than 1·5 volts. After soaking for twelve hours in the sal ammoniac solution, the resistance of each cell should not be greater than 1 ohm, the No. 0 type cells being tested with two zinc rods, other types with one.

The polarisation is ascertained by shunting the cell with 2 ohms for ten minutes and then measuring the open circuit E.M.F. immediately after the shunt circuit is broken. The difference between this voltage and the original open circuit E.M.F., expressed as a percentage of the latter, should not exceed 15 per cent. for the

No. 0 and No. 1 types, and 20 per cent. for the No. 2A and No. 2A oval types.

Output.—Of the cells delivered, 2 per cent., drawn at random, are tested for output in a 15 per cent. sal ammoniac solution with a rod zinc (two in the case of the type No. 0), discharging at the current value shown below for average periods of five hours per day for six days per week, until the E.M.F. of the cell falls to 0·975 volt. The voltage of the cell is measured on open circuit immediately after disconnection at the end of the day's discharge. The zinc and excitant are renewed as their condition demands during the output test. The minimum output should be not less than that shown below :—

Type No.	Discharge Current.	Output, Watt-hours.
0	100 milliamperes	200
1	50 "	60
2A	20 "	24
2A oval	20 "	24

The tests are made in the same way as for dry cells.

Leclanchè Wet Cells (Sack Type).—The complete element comprising the depolarising mixture, carbon rod, terminal and wrapping of canvas is referred to as a " sack " cell.

The external dimensions of the sack cells should be in accordance with the figures given in the following table :—

Type No.	Diameter.	Maximum Overall Height.	Major Axis.	Minor Axis.
	ins.	ins.	ins.	ins.
0	4¼	9	—	—
1	3¼	9	—	—
2A	2⅛	7	—	—
2A oval	—	7	2½	1¾

The brass terminal should be securely leaded in to the carbon rod, and pinned to the rod or prevented from turning or working loose by some other effective method. The sack cell should be efficiently sealed and ventilated, but any tube used for the purpose must not project above the sealing compound. The top of the carbon rod, and also the sack cell for ½ inch below the level of the sealing compound, should be waxed in order to prevent creeping. The depolarising mixture of manganese dioxide and carbon surrounding the carbon rod should be in the form of fine powder, of the quality described below, and should be well packed.

Tests.—The initial open circuit E.M.F. of a complete cell (consisting of a rod zinc in a 15 per cent. by weight solution of sal ammoniac in water and a sack cell) should be not less than 1·5 volts.

Resistance and Polarisation.—After being soaked for one hour in the sal ammoniac solution, the resistance of all sizes of cells should not exceed 1 ohm, and after twelve hours the resistance should not exceed 0·75 ohm and the polarisation 10 per cent. for the No. 0 and No. 1 cells, and 12·5 per cent. for the No. 2A and No. 2A oval types. The polarisation is determined in the same way as for porous cells.

Quality and Quantity of the Depolarising Mixture.—A sample of the depolarising mixture is dried and tested chemically for the amount of available oxygen and the percentage of pure manganese dioxide calculated therefrom. The percentage so calculated should not be less than 60 per cent. (by weight) of the dried sample taken.

The quantity of depolarising mixture by weight should not be less than the amounts shown below :—

Type.	Weight of Depolarising Mixture.
No. 0	8 lbs.
„ 1	3¼ „
„ 2A	1¼ „
„ 2A oval	1¼ „

In estimating the amount of manganese dioxide in the depolarising mixture the following method is convenient. About 10 grammes of the mixture are dried at 100° C. till they cease to lose weight. The 10 grammes are finely ground in a mortar, and 2 grammes of the dry mixture are weighed out and put into a 200 c.c. flask fitted with a Bunsen valve. 50 c.c. of normal oxalic acid solution and 5 c.c. of sulphuric acid in 15 c.c. of distilled water are added. The flask is warmed till all action ceases, and then the solution is gently boiled for a few minutes and filtered. The filtrate is heated to 60° C. and titrated with semi-normal permanganate till a faint permanent pink colour is obtained. Subtracting half the number of cubic centimetres of permanganate used from 50 and multiplying by 2·175, gives the percentage of manganese dioxide in the mixture. A detailed description of volumetric processes will be found in Sutton's "Volumetric Analysis."

When manganese dioxide is purchased separately for use in batteries, the ore is required to comply with the following paragraphs, which have been extracted from the Post Office Specification :—

"The manganese to pass through a standard sieve having 40 meshes to the inch, but to remain on a standard sieve having 60 meshes to the inch.

"The manganese to contain not less than 84 per cent. of pure peroxide, the percentage of peroxide being arrived at by means of a sample taken from bulk and dried at 212° F. until it ceases to lose weight. Any loss of weight on drying in excess of 1½ per cent. will be deducted in determining the weight to be paid for."

The method of estimating the percentage of peroxide (manganese dioxide) is similar to that described above.

Ammonium Chloride.—This salt was for many years purchased

in a crystalline form, the size of the crystals being restricted so that they were in average agreement with the Post Office pattern sample. The largest crystals were about $\frac{3}{4}$ inch long by $\frac{1}{4}$ inch approximate diameter, and the smallest about $\frac{3}{16}'' \times \frac{1}{16}''$. The reasons for restricting the size of the crystals are to ensure reasonably quick solution when refreshing batteries, and to obviate any tendency for small crystals to coalesce or pack during transit. If the crystals pack it is very difficult to remove the salt from the cask. It may perhaps be mentioned that ammonium chloride crystals are not commercially the same article as sal ammoniac. The latter is frequently used with soldering irons, and is in the form of large fibrous blocks. To get the ammonium chloride in this form it is necessary to sublime it. The cost of this process causes the price of sal ammoniac to be higher than that of ammonium chloride. At the present time the Post Office supplies consist almost entirely of flat discs of ammonium chloride, probably produced by pressure, about $\frac{5}{8}$ inch diameter, $\frac{1}{4}$ inch thick, each weighing about $1\frac{3}{4}$ grammes, and known commercially as "Voltoids." The discs are very dry and of high quality, but they dissolve somewhat more slowly than the small crystals formerly used. The following paragraphs are taken from the Post Office Specification for crystalline chloride of ammonia :—

"The loss on drying at 212° F. shall not exceed 2 per cent.

"The oxide of iron, and other impurities present, shall not exceed 0·15 per cent., and the residue, after sublimation, shall not exceed 0·1 per cent.

"The chloride of ammonia shall, as to the size of crystals, be to a sample which will be supplied."

To ascertain the residue after sublimation, it is convenient to heat gently about 20 grammes of the salt in a platinum crucible until all the volatile matter is driven off. The residue generally consists of sodium and magnesium chlorides and sulphates and oxide of iron. If the sublimation is carefully carried out all the iron is in the residue, and can be estimated by dissolving in HCl, oxidising with a little nitric acid, precipitating with ammonia and weighing as Fe_2O_3. To estimate the ammonium chloride, about $1\frac{1}{2}$ grammes are dissolved in distilled (recently boiled) water in a wide-mouthed flask, and 40 c.c. of normal caustic soda added. The solution is then boiled until all ammonia is driven off, which can readily be ascertained by trying the steam with a red litmus paper. After cooling down the soda is titrated with normal sulphuric acid. The number of cubic centimetres of normal soda used to expel the ammonia, multiplied by ·053, gives the weight of ammonium chloride in the sample taken. Methyl orange or litmus can be used as an indicator. The chlorine can be estimated volumetrically with normal silver nitrate if desired. As the result of some research work done by Mr. J. G. Lucas,* of the Post Office, manganese chloride is

* Proc. No. 35, I.P.O.E.E. "The Life and Behaviour of Primary Batteries," by J. G. Lucas.

used in place of ammonium chloride in some Leclanché batteries used for terminal or subscribers telephones where only a small ampere-hour capacity is required. It possesses the advantage that no fumes of ammonia are given off by the battery. Ammonia attacks the metal parts of telephones, etc., and further necessitates free ventilation, with consequent evaporation and subsequent recharging to make up the water lost. The frequent recharging increases the maintenance cost of the battery considerably. With manganese chloride there is no need for ventilation; in fact, it is preferable to seal up the battery box, as a brown oxide forms if manganese chloride is freely exposed to the air. The following paragraph is extracted from the Post Office Specification for manganese chloride :—

"To contain not less than 98 per cent. of pure manganese chloride, the total amount of iron soluble and insoluble not to exceed 0·1 per cent.; the moisture not to exceed 1·5 per cent. To be free from dirt and extraneous matter."

Commercial supplies of manganese chloride are usually very pure, and it is generally sufficient to estimate the percentage of chloride only. This can conveniently be done by weighing out 9·9 grammes of the sample, dissolving in distilled water, and making up the volume to exactly 1 litre; 50 c.c. of this solution are then titrated with decinormal silver nitrate (using potassium chromate as an indicator) till a faint orange colour is permanent. The number of cubic centimetres of silver nitrate used, multiplied by 2, gives the percentage of $MnCl_2 . 4H_2O$ present.

Estimation of Iron and Insoluble Matter.—It is convenient to dissolve 25 grammes of the manganese chloride in distilled water, filtering off any insoluble matter, which should be weighed if present. To the filtrate add a few drops of nitric acid and about 20 c.c. of hydrochloric acid and heat for twenty minutes. Neutralise with ammonia, using a considerable excess, and add strong ammonium chloride solution till the bulky precipitate first formed is dissolved, leaving only the precipitate of ferric hydroxide. Filter and redissolve the ferric hydroxide in dilute hydrochloric acid, reprecipitate with ammonia and ammonium chloride filter, and repeat this operation, finally filtering, washing, drying, igniting, and weighing as Fe_2O_3.

The iron is usually present in the original sample in the form of ferrous chloride. The moisture can be obtained by difference. The sum of the percentage of $MnCl_2$ $4H_2O$ and the percentage of $FeCl_2$ $4H_2O$, subtracted from 100, gives the percentage of moisture present.

Copper Sulphate.—The following paragraphs are extracted from the Post Office Specification :—

"To contain not less than 99 per cent. of pure crystalline sulphate of copper, not more than 0·15 per cent. of crystalline sulphate of iron (green vitriol), and not more than 0·85 per cent. of extraneous water.

"To be sifted *dry* through two sieves of punched copper plate, the first with holes ¼ inch in diameter and the second with holes ¾ inch in diameter, so as to eliminate powdered sulphate and crystals of too large a size."

To estimate the impurity, 25 grammes are dissolved in distilled water, and if anything insoluble is present, this is filtered off and weighed. To the filtrate a few drops of nitric acid are added to oxidise the iron, and then an excess of ammonia, till the copper precipitate first formed is dissolved. The ferric hydroxide is filtered off, redissolved in dilute hydrochloric acid, and reprecipitated with ammonia, filtered, dried, ignited, and weighed as Fe_2O_3. The Fe_2O_3 found is calculated to $FeSO_4, 7H_2O$, and expressed as a percentage of the original weight taken.

Owing to the crystals being of comparatively large size, it is very seldom that the extraneous water exceeds the limit allowed by the specification. If an accurate determination of the extraneous water is found to be necessary, this is best ascertained by difference, because drying at 100° C. is liable to drive off part of the water of crystallisation. The filtrate from the iron determination is boiled until all the ammonia is expelled, sodium carbonate is added to neutralise any free acid and until a precipitate occurs, then acetic acid until the precipitate is redissolved. A solution of potassium iodide is added in excess, and the liquids thoroughly mixed. The amount of free iodine liberated is then titrated with standard sodium thiosulphate solution, until the free iodine is nearly removed, a few drops of starch solution are added, and the titration proceeded with till the colour is discharged. If $\frac{N}{10}$ sodium thiosulphate is used, each cubic centimetre of the solution is equivalent to ·0063 gramme of copper. The copper is calculated to $CuSO_4 . 5H_2O$ and expressed as a percentage of the weight taken. The sulphur may be estimated gravimetrically by precipitation with barium chloride, but this determination is seldom necessary. The sum of the percentages of $FeSO_4, 7H_2O$, and $CuSO_4\ 5H_2O$, subtracted from 100, gives the percentage of extraneous water in the absence of any insoluble matter.

Zinc Rods for Leclanché Cells.—The following paragraphs have been extracted from the Post Office Specification:—

"A pattern zinc rod will be lent to the contractor for general guidance in manufacture. The zinc rods supplied by the contractor shall be equal to the sample as regards size and make up, and shall not be inferior as regards quality of materials, electrical properties, and behaviour. They shall be capable of being subjected to a five hours per day for six days per week 'length of life' test, up to the point at which, in the opinion of the Engineer-in-Chief, the practical qualities of the rod remain unimpaired, and under these conditions the rods shall be of such quality as will permit of at least 70 per cent. of their substance being absorbed by the chemical action.

"The connecting wire on the zinc rod shall be 7 inches long and

of 26 S.W.G. stranded conductor, with the free end soldered or otherwise prepared to avoid fraying and to give good electrical connection. It (the connecting wire) shall be insulated with a covering of impregnated cotton or other suitable material, the insulation to be made continuous with the top of the zinc rod by means of insulating compound.

"Six sample zinc rods shall be returned with the tender form, and these will be taken as representing the exact article tendered for."

CHAPTER X

TELEPHONE TRANSMITTERS AND RECEIVERS

TRANSMITTERS and receivers are tested by a comparison method under approximately practical conditions, the comparison being made with standard apparatus, specially chosen and standardised for the purpose. The most important requirement in using a comparison method is that the standard apparatus shall not vary during the test. This requirement is not difficult to comply with as regards the receiver, but it is a different matter where the transmitter is concerned. Some types of transmitter will vary considerably from test to test, varying not only when spoken into by different people, but even with the same speaker. It is obvious, therefore, that the choice of a standard transmitter is not an easy matter, and a long and careful investigation is necessary before definitely deciding upon the type to be adopted. Fortunately, the purchaser is not the only person who needs a standard for comparison purposes, as the manufacturer knows that his transmitters will soon prove unsaleable unless he takes steps to ascertain that they are within the necessary limit of constancy. The makers of telephone transmitters, therefore, are in their own interest bound to investigate the effect of any small change in dimensions, materials—especially carbon granules—and assembly before altering anything in their productions. It is to the manufacturers that the credit is due that standard transmitters which are practically constant are available, and the Post Office Research Department, after an exhaustive investigation, have adopted as the practical standard transmitter with which to compare all others the Western Electric Company's Solid Back Transmitter, No. 4001. The matter, however, is periodically reviewed, but that is the position at the present time. Even the best transmitter may be damaged by some mishap, and it is necessary, therefore, not to rely upon a single sample, even if this were practicable, and consequently it is desirable to keep a fairly large batch—say twelve—the characteristics of which have been accurately determined, and to retest them periodically, eliminating any that show evidence of abnormal tendency, and replacing them by new ones. In addition, it is desirable to have some reference standard that does not depend upon a microphone contact, and a transmitter of the telephone Bell receiver type at once suggests itself. Needless, perhaps, to say the Post Office Research Department have electromagnetic transmitters of this type, but of special dimensions, etc.

Having decided upon a standard, it is not difficult to ascertain the speech efficiency of any particular transmitter. Where large supplies of telephone transmitters have to be tested, it is convenient to test the bulk at the manufacturer's works, and consequently secondary standard transmitters have to be provided for this purpose. These are balanced against the primary standards and then sealed and labelled with their standard values and brought into practical use. The secondary standards are returned periodically—every six months at least—for re-comparison with the primary standards, and those that show any abnormal change are replaced by new secondary standards. In the routine test the secondary standard is not used, but a working standard is chosen by the Testing Officer, and is used for the purpose of comparison with supplies. The secondary standard transmitter is kept in reserve for comparison only with the working standard; check tests against the secondary standard being taken at least every morning before testing begins and after the interval for the midday meal, and at any other times where the routine test indicates that it is desirable.

Being provided, then, with standards of reference, what are the characteristics of the transmitter that have to be safeguarded in the bulk supplies? Mainly there are only three, namely, the volume of speech transmitted, the articulation, and the ohmic resistance. The other characteristics such as (1) side tone; (2) tendency to pick up extraneous noises; (3) frying; and (4) packing, are in general functions of the design of the transmitter, which are better ascertained under Research Laboratory conditions than in a works test. If the design of the transmitter is satisfactory, points (1), (2), (3), and (4) can in general be ignored in the routine test, although it is the practice to test a few transmitters from each day's supply with regard to packing, frying, etc., and to report immediately to the Research Department if anything abnormal is detected. If the transmitter is below standard, as regards liability to pack, it can generally be detected by speaking into it in a soft tone for a few minutes. If the transmitter packs, the volume of speech transmitted will fall off considerably after two or three minutes speaking. Liability to "fry" or crackle is generally most evident on a zero loop, which will be referred to later. "Side-tone" is the unpleasant loudness that is heard in the home receiver when the home station is speaking, but is seldom met with in modern supplies, as the trouble has been to a large extent overcome by improvements in design. A similar remark applies to the super-sensitiveness of some transmitters to pick up extraneous noises. Articulation is, of course, of first importance, but the distinctness of the speech received is checked in the routine test, and is taken care of by this means.

The next requirement that has to be met before the transmitter can be tested under routine conditions is the provision of a standard telephone circuit. It is obvious that this should approximate as nearly as possible to practical conditions, and consist of subscribers' ends, a model exchange, and an artificial telephone line. It is

necessary, therefore, to specify circuits for the three main classes of telephone transmission, viz., (1) common battery; (2) local battery; and (3) automatic. The standard circuits are shown in Figs. 54, 55, and 56. It will be noticed that all the apparatus used in the

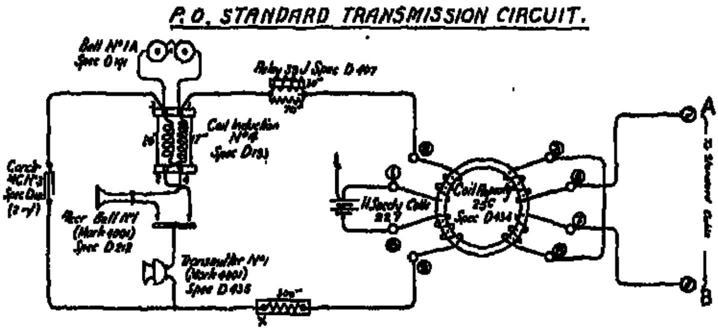


FIG. 54.

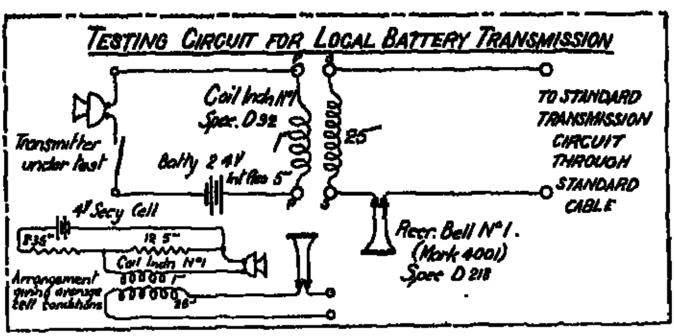


FIG. 55.

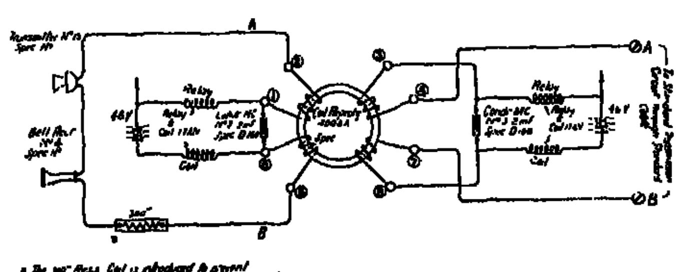


FIG. 56.—Standard Transmission Circuit for A.T.M. Co.'s Auto System.

circuit has a definite type designation, and apparatus of the type stipulated only is used for the purpose of the test. It is obvious that the substitution of a different type of induction coil, relay, repeating coil, etc., would alter the value of the circuit as regards transmission

efficiency. Without the 300 ohm resistance the standard common battery circuit is referred to as "zero local loop," and all efficiencies are stated in terms of "zero local loop." The effect of the insertion of 300 ohms in the zero local loop is equivalent to inserting in the main line 10·2 miles of standard cable when regarded as a transmitting circuit, and 1·5 miles of standard cable when regarded as a receiving circuit. The number of ohms inserted in the circuit is taken at 300, because it happens to be convenient and corresponds approximately to the highest resistance usually occurring in a subscriber's line. There is no particular virtue about the number 300, but the standard cable equivalent of that resistance, when put into the circuit, has been accurately determined, and it is advisable not to use too big a current in the circuit under common battery and automatic conditions—which the insertion of the 300^{ω} prevents—as it is apt to cause the working standard transmitter to deteriorate. In the testing it is important to fit the transmitters in a definite position in the holding device. It is obvious that if the front and back carbon plates of the transmitter cell are not absolutely parallel, the relative distribution of the granules will not be the same in all positions of the transmitter. It is the practice to fit the transmitter so that the identifying mark number is in the highest position and symmetrical about a vertical diameter. Further, the transmitter is fixed with its front in a vertical plane for the purpose of testing speech efficiency, but is tilted backwards through 25° for the resistance test. This tilting backwards, of course, affects the ohmic resistance, the transmitter offering a somewhat higher resistance in this position than it does when fitted vertically. The resistance is ascertained by means of a voltmeter across the transmitter and an ammeter in series.

It is usual to arrange for a resistance equal to the specified limiting figure to be thrown into circuit in place of the transmitter when it is desired to calibrate the voltmeter. This obviates the need of an ammeter. The measurement is only an approximation, but it is sufficiently near for practical purposes. In the routine test there is generally no need to get an exact balance against the working standard, it being sufficient to ascertain that the transmitter under test is equal to the working standard transmitter under the same conditions. An exact balance, however, is necessary when choosing or checking the working standard, and the following method of procedure is generally observed. The test is made by two persons, one speaking and in charge of keys and apparatus, and one listening. The speaker repeats the words, "One, two, three, four, five," in as clear, even, and uniform a voice as possible, followed by the letter A for the secondary standard and B for the working standard successively in the two transmitters, throwing the keys alternately as required. Nothing is changed, except that one transmitter and its balancing cable is substituted for the other, the same main cable and receiving end being used for both transmitters. The listener reports which is the better, whether A or B, but he does not

know what value of cable is in circuit, that being under the control of the speaker. The result is recorded and a change made in the balancing cable at the discretion of the speaker. The test is repeated and again recorded. When half a dozen such changes have been made the result is generally sufficiently well indicated. The two persons then change over and a further set of tests is made, starting with a slight out of balance in each case.

If the results of the two sets of tests agree the working standard is approved, but it is preferable to have three sets of tests if three testing officers are available. If the results are not reasonably near, it is probable that the transmitter is not sufficiently constant under all conditions to prove satisfactory as a working standard, and other transmitters are therefore selected and tested until a satisfactory working standard is obtained. The working standard is always of the solid back type, no matter what type of transmitter is being tested, as the solid back is generally more constant than other types. Further, the comparison is always made between the standard common battery circuit and whatever other circuit may be involved, i.e. local battery or automatic. Commercial speech is practicable over 46 miles of standard cable on the standard common battery circuit with 300w. subscriber's lines, and this is the accepted standard.

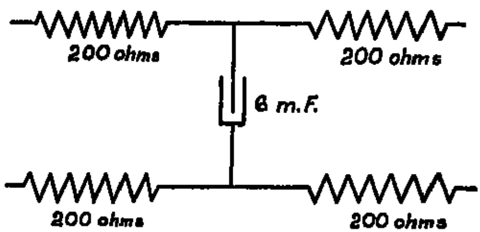


FIG. 57.—Artificial Cable.

Supplies of Transmitters No. 1 (Western Electric Company's type 4001) are approved by the Post Office if the average efficiency of the transmitters is within 2½ miles of standard cable of the accepted standard, and no transmitter is approved that is more than 5 miles of standard cable below the accepted standard.

All other circuits and apparatus may be expressed in terms of this standard. For a description of standard cable and artificial cables the reader is referred to Volume I. For the routine test 30 miles of artificial cable are found to be convenient in the main circuit. Although 46 miles can be used, it is unduly tiring to the testing officer to work on almost the commercial limit of speech, and there is no need to use it, seeing that the test is merely a comparison with a standard. The balancing cable can be quite conveniently a small one, with a range of 1 to 10 miles in steps of 1 mile. Since the main cable is common to both tests, the 30 miles of standard cable may be made up of a lumped resistance and capacity as shown in Fig. 57 if a box of artificial cable is not available. It is not practicable to balance transmitters closer than to 1 mile steps, that is to say it is practically impossible in routine tests to detect a smaller difference in speech transmission than is caused by the

addition of 1 mile of artificial cable. In the routine test, therefore, it facilitates matters to handicap the test transmitter (not the working standard) by 2 miles of artificial cable, as this arrangement shows up more readily any doubtful transmitters, which, when found, can be put aside and balanced accurately later in the day. If there is no marked difference when the test transmitter is handicapped in this way, it is probable that it is up to or better than the required standard of speech efficiency, and may be approved. Every transmitter purchased is compared with the working standard, but the test seldom takes more than about half a minute when the supplies are uniformly satisfactory. An expert testing officer can detect a defective transmitter immediately he hears the first set of words, "One, two, three, four, five," and he signals back to the speaker by means of a press button and trembler bell as follows:—

One short ring for transmitter satisfactory.
Two short rings for speak again on working standard and then on transmitter under test.
Three short rings for speak on the service telephone which is provided for the purpose.

The listening end should always be housed in a silence cabinet or sound-proof room. The speaker must not vary his position with regard to his distance from the mouthpiece when speaking on the transmitters, or errors will result. It is a good rule to require the speaker to allow his upper lip to touch the top of the mouthpiece when speaking, so as to ensure uniformity in the testing conditions. If this rule cannot be applied, e.g. hand micro-telephones, the distance from the mouthpiece should be determined and fixed by means of a simple testing jig. Usually hand micro-telephones are tested by speaking at a distance of 1⅛ inches from the edge of the mouthpiece, a ring or other device being fitted on the testing jig to mark the exact distance. Obviously all human faces are not exactly the same size, and consequently when a hand micro-telephone is used, since the receiver is held against the ear, the mouthpiece of the transmitter will not be at the same distance from the speaker's lips in all cases. The effect of varying this distance is considerable, as will be seen from the curve shown in Fig. 58, hence the need to test at a fixed distance. The speech tests of C.B. transmitters are considerably facilitated and expedited when the transmitters are tested at manufacturer's works if they come to the testing officer with the backs not screwed on. Arrangements can then be made to fit the essential portion of the transmitters in spring clamp connectors mounted on boards, each accommodating half a dozen transmitters. The boards are filled by assistants, and when placed in a testing jig make the necessary contacts automatically. The inspecting officer's time is consequently not taken up in making connections, and the speech tests go on without intermission, each position keeping two or three assistants filling, changing, and refilling the boards. The working standard transmitter is not moved, but is

fixed independently of the boards, and is spoken over as required by the listener. To prevent any packing it is smartly tapped with a lead pencil every five or six minutes. It will be noticed in Fig. 48 that if 46 miles of artificial cable be inserted the total number of miles of standard cable spoken over—when allowance is made for the 300 ohms resistance—is 10·2 + 46 + 1·5 = 57·7 when reduced to zero local loop. The *Local Battery* circuit, of course, does not require any allowance for the subscriber's line, as is the case with the common battery circuit, and if 46 miles of standard cable are specified the total number of miles of standard cable in this case is 46 + 1·5 = 47·5, or 10 miles less than C.B. on zero local loop. The local battery transmitter, therefore, is said to have an allowance of 10 miles of standard cable. The local battery testing circuit is shown in Fig. 55. In the case of hand micro-telephones, it is necessary to increase this allowance to 16 miles of standard cable when tested $1\frac{1}{8}$ inches from the mouthpiece. Hand micro-telephones are consequently very inefficient when compared with C.B. and with the A.T.M. Company's automatic, which are practically equal in transmission efficiency under Post Office requirements. Operator's C.B. breastplate transmitters have an allowance of 8 miles of standard cable when tested in the standard C.B. circuit. (*N.B.*—Not the operator's circuit.) Special methods are followed in testing electrophone, fire alarm, and other particular transmitters, but they need not be described here.

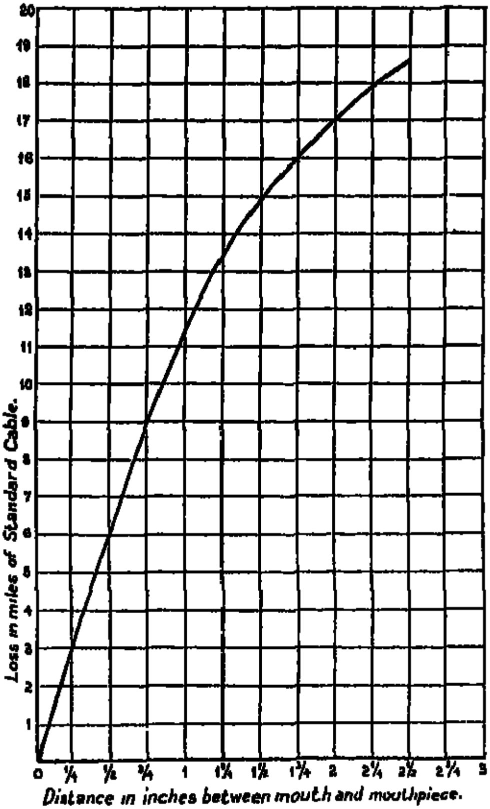


FIG. 58.—Loss in Efficiency caused by Speaking at Various Distances from the Mouthpiece.

When testing the transmitter used in the automatic circuit, the automatic circuit shown in Fig. 56 is used, and connected through an artificial cable to the C.B. circuit (Fig. 54). The special

transmitter used in the automatic circuit must be equal to the standard C.B. transmitter when the two transmitters are connected to their proper circuits, that is to say, the transmitting efficiency of the automatic circuit must be equal to the transmitting efficiency of the standard C.B. circuit.

In view of the important functions performed by the transmitter, it is advisable to examine every transmitter for possible mechanical defects. Occasionally screws will be found to be overturned, that is, they can be turned indefinitely without tightening up, the brass screw of the mouthpiece may be too long and foul the diaphragm, some connections may be ineffectively soldered, facilities for adjusting the electrodes may be inadvertently omitted or be insufficient for the purpose, vent holes may be omitted in mouthpieces for breastplate transmitters, etc. Some of these defects would show up, of course, in the speech test, but others might go undetected unless a mechanical examination were made and would cause trouble in practice.

Receivers.—The same circuit arrangements are used in testing telephone receivers as in testing telephone transmitters, and the method followed is also one in which comparison is made with a standard instrument. The standard adopted by the Post Office is the double pole Bell receiver made by the Western Electric Company, and bearing their mark number 4001. As in the case of transmitters it is advisable to have a fairly large batch of primary standards, and to test them periodically, eliminating any that are found from any cause to have deteriorated. It is usual to seal the ear-pieces of the standard receivers, so that they cannot be taken off. This is important, as any rearrangement of the clamping of the diaphragm may alter the efficiency of the receiver 2 or 3 miles. The secondary standards are also sealed, but this precaution is not adopted with the working standard, as the secondary standard is always available for comparison when necessary. It is usual to handicap the receiver under test by 2 miles of artificial standard cable, as in the case of transmitters, and for the same reason. The procedure followed in testing receivers is practically the same as in testing transmitters. The working standard can seldom be chosen of the exact value, and consequently the adjustable cable is required to take charge of this difference, as well as the 2 miles handicap above referred to. The ear-pieces of the receivers should be screwed up tightly before the speech test is made. Occasionally the diaphragm is not satisfactorily clamped by the ear-piece, and the receiver will fail in the speech test. Fitting a fresh ear-piece will sometimes bring the receiver up to standard. The distance between the pole pieces and the diaphragm is perhaps the most important dimension in the receiver, and it is advisable to have a micrometer depth gauge available for measuring this distance. A suitable type of depth gauge is made by the Automatic Telephone Manufacturing Company, Milton Road, Edge Lane, Liverpool. It is graduated in mils. The receiver electro-magnets and case should be quite free from metallic

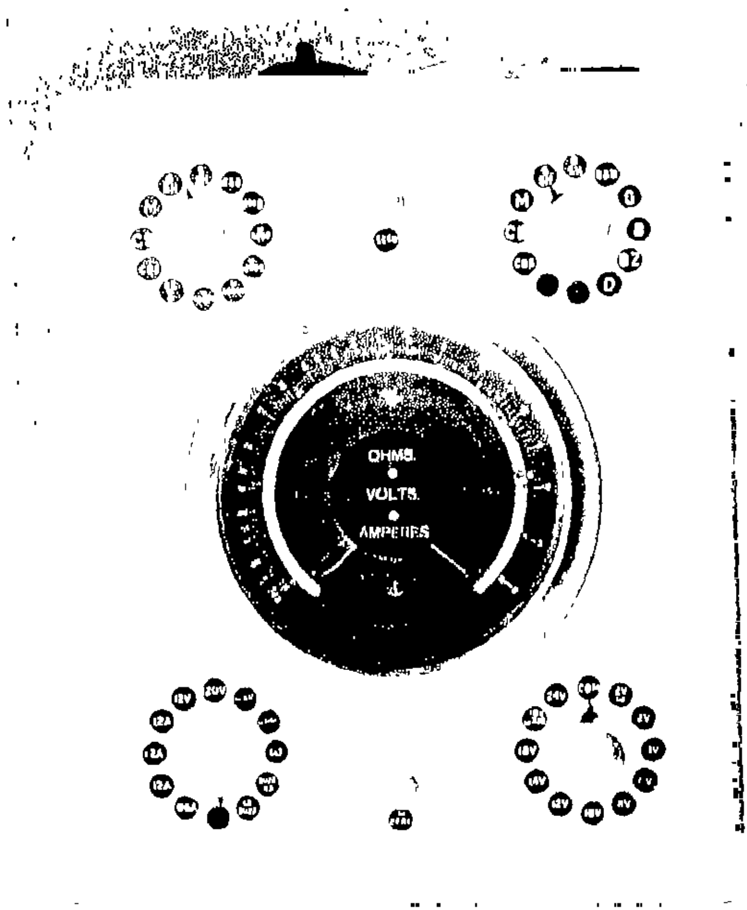


Fig. 61.—Combination Testing Set.

particles and dust, especially the metallic particles ground from the pole pieces in the final adjustment of the receiver. Unless the case is clean the foreign matter will in time work its way in between

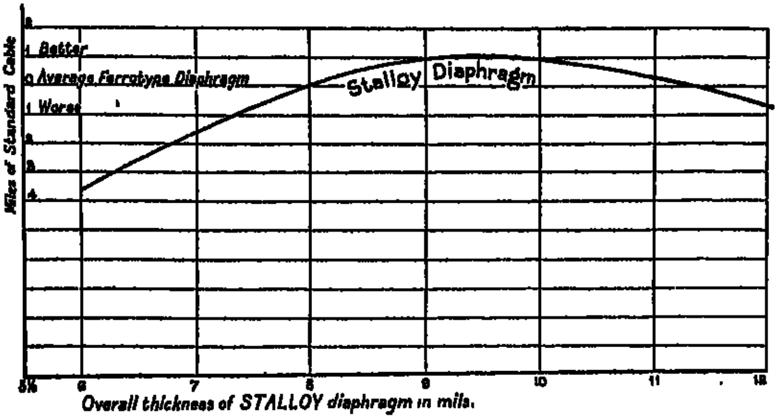


FIG. 59.—Efficiency of Stalloy Diaphragms of Various Thicknesses.

the pole pieces, and will probably seriously reduce the efficiency of the receiver. For Post Office requirements Stalloy diaphragms are used, and it is an interesting fact that the thickness of the Stalloy diaphragm has a marked influence on the speaking efficiency of a receiver. The variation of efficiency with thickness of diaphragm is shown in Fig. 59, and it will be noticed that a diaphragm with an overall thickness of 9 to 10 mils gives the best result.

In addition to the speech test, the ohmic resistance of the receiver is measured as a check on the number of turns of wire on the electro-magnets, and an insulation test is taken to prove that there is no considerable leakage between the coils and the case. The value of the flux in the permanent magnets can be ascertained by means of the Grassôt fluxmeter, but the value is not specified by the Post Office. As a rough test of the magnetisation an iron keeper weighing 16 ounces is sometimes used, a Bell receiver being considered under-magnetised if it will not lift the keeper. The form of the iron keeper is shown in Fig. 60. A similar keeper is used for watch receivers. It weighs 6¾ ounces, the dimensions being the same except that the height of the lower cylinder is $\frac{11}{32}$ inch.

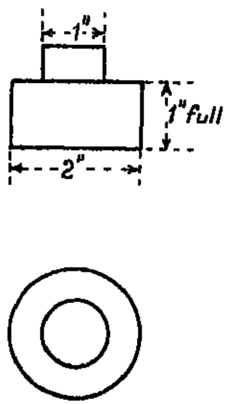


FIG. 60.—Iron Keeper used for Testing Receivers.

The surfaces of the pole pieces should be in the same plane and parallel to the diaphragm. Where riveted permanent magnets are used they occasionally show hardening

cracks near the rivets, and when cracks are detected the magnets are rejected. The poles of the permanent magnets must be arranged to suit the winding of the electromagnetic coils in C.B. instruments, otherwise the common battery will tend to demagnetise the permanent magnets. It is usual to mark the case and the N pole of the magnet, to enable the winding to be arranged correctly. The edge of the cord hole in the receiver case should be smooth and well-rounded, so as not to cause damage to the cord. The ebonite ear-piece should be left tough from the vulcanising process. A good tough ear-piece will stand dropping on a stone floor from a height of 15 feet without chipping or cracking or other sign of deterioration. If brittle ebonite is used for the ear-piece it will be found in practice that the ear-pieces will frequently break under quite ordinary usage, and the cost of replacing them, especially when the subscribers' station is a long way from the exchange is out of all proportion to the cost of a good ear-piece. Since the weight of the Bell receiver is generally used to operate the automatic switch on table and wall telephones, it is necessary to see that they do not fall below a minimum weight of 13 ounces.

The following schedule of allowances shows the Post Office requirements as regards transmission in terms of zero local loop :—

Type of Instrument.	P.O. Type Numbers.	Allowance in Miles of Standard Cable.	Maximum Resistance Tested at an angle of 25°.
Transmitters :—			
Solid back . . .	No. 1	Average 3½, Maximum 5	70 ohms
A.T.M. Company's solid back (tested on automatic circuit against standard C.B. circuit)	No. 11, No. 12, and No. 15	Average 3½, Maximum 5	70 ,,
Breastplate . . .	No. 5	8	Not specified
Inset for local battery working . . .	No. 3	10	25 (minimum)
Micro-telephones (tested at 1½ inches from edge of mouthpiece) . .	No. 28	16	Not specified
Receivers :—			
Double pole bell . .	No. 1	2	60 ohms
A.T.M. Company's electromagnetic (tested on automatic circuit against standard C.B. circuit) . . .	No. 4	2	—
Headgear . . .	No. 1A and No. 3A	5	60 ohms
,, . . .	No. 1B and No. 3B	5	150 ,,
Watch . . .	No. 1 and No. 2	5	150 ,,

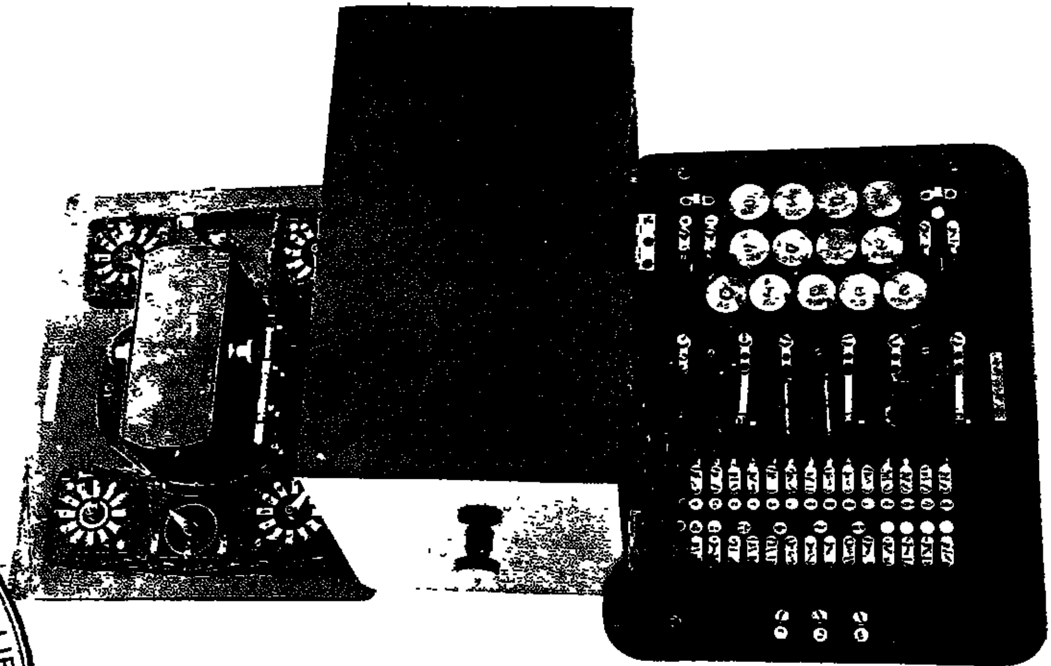


Fig. 62.—Combination Testing Set. Bottom View with Doors Open.

CHAPTER XI

ELECTRICAL TESTING OF TERMINAL TELEPHONES

TERMINAL, or as they are usually called, subscriber's telephones are purchased in large numbers, and since the same tests have to be applied to each set of the same type, the provision of special testing appliances to facilitate and expedite the work is advisable. One of these appliances is the combination testing set. This was first introduced by the National Telephone Company, and has since been modified and adopted by the Post Office. It provides facilities for—

(a) Testing hand-ringing generators and magneto bells.
(b) Ascertaining the working or figure of merit currents of relays, indicators, etc.
(c) Measuring resistances, currents, and potential differences.
(d) Proving disconnections, contacts, and continuities.
(e) Connecting to common battery and common battery signalling exchanges, and to similar combination testing sets in the same room.

A high degree of accuracy in these tests is not necessary, the principal requirement being to ascertain whether the terminal telephone will or will not function satisfactorily. Supplementary tests can, of course, be applied with more sensitive instruments where the results obtained from the combination testing set indicate that such a course is desirable, but such tests are, generally speaking, quite exceptional. Figs. 61 and 62 are photographs of the set, and Fig. 63 is a diagram of the internal connections. The front panel of the case accommodates :—

A moving coil instrument.
Four switches, each switch having twelve positions (A, B, C, and D). (Fig. 63.)
An ebonite knob marked "zero," which mechanically sets the indicator of the moving coil instrument to zero ; and
An ebonite knob marked $\frac{\text{"}\omega\text{"}}{\text{zero}}$, which forms part of a 2-ohm compensating rheostat, the function of which is to correct any variation in the voltage of the ohmmeter battery.

The indicating instrument in the middle of the set is a voltmeter of the Record Electrical Company's make, re-calibrated and arranged

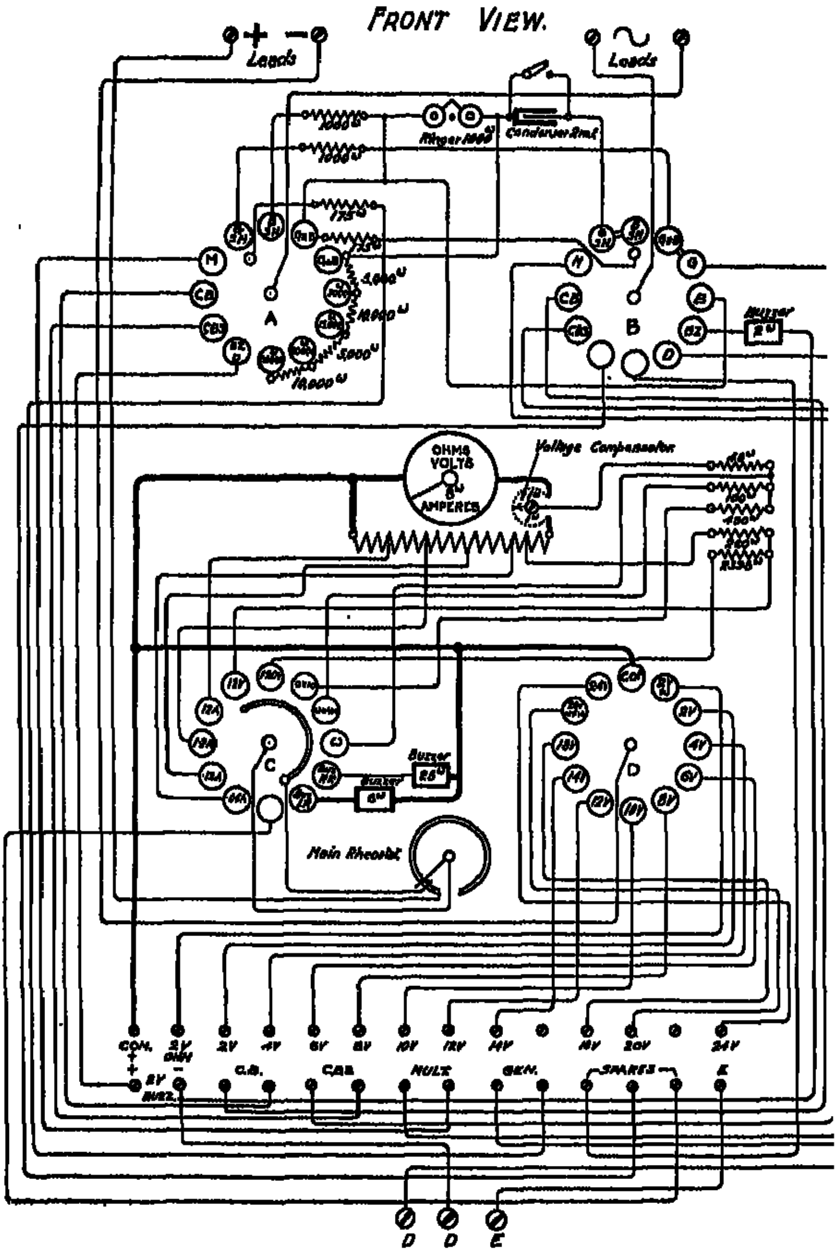


FIG. 63.—Combination Testing Set, Diagram of Connections.

for use as an ohmmeter, voltmeter, and ammeter. It has an exceptionally long scale (nearly 260 degrees), and is well adapted for telephone work. The knob between the two switches near the top of the set enables the needle of the instrument to be mechanically set at zero. The scale for current and volt readings is divided into twelve equal divisions and subdivided into tenths. The ohms scale is specially calibrated and marked above the other scale. In practice it is found convenient to compensate for the testing leads so that in resistance measurements, the instrument reading is independent of the resistance of the leads. To accomplish this the flexible leads, which are generally suspended from the ceiling and fitted with balance weights, so that when they are not required they can be raised out of the testing officer's way, are chosen so that they offer less than 2 ohms resistance, and are brought up to this value on a small compensating rheostat adjustable by means of the knob between the two lower switches. The ohms scale is calibrated with this 2 ohms in circuit. To check the compensation for the leads, they should be short circuited, and the needle of the instrument should then indicate zero with the lower left-hand switch arm on terminal stud *w*; and 100, with the switch arm on terminal stud marked *w* + 100. With the switch arm on terminal stud *w*, the range of the ohms scale is from 0 to 2000 ohms, and with the arm on terminal stud marked *w* × 10, the range is from 0 to 20,000 ohms. Currents ranging from 0·5 milliamperes to 12 amperes can be measured by putting the switch arm on the studs marked ·06, ·12, 1·2, 12, the value of the scale division being 5, 10, 100 milliamperes and 1 ampere respectively. Voltages ranging from 1 to 12 and 10 to 120 can be measured with the switch arm on terminal studs 12 v. and 120 v. respectively. For current and voltage measurements the lower right-hand switch arm is put on terminal stud marked Com. The other terminal studs on this switch are connected to a battery of accumulators having the values shown in Fig. 63. The stud marked 2 v. ohms is connected to a separate accumulator cell, which is used for resistance measurements only. The main rheostat connected to the lower left-hand switch is used for the adjustment of currents only, and is short circuited automatically when the switch arm is on any stud other than those used for current measurements, such as are required in applying working or figure of merit currents to indicators, relays, etc. Certain types of hand-ringing generators have to give a commercial ring on a standard magneto bell when connected, as shown in Fig. 64. This test is provided for on the two upper switches, when the switch arms are placed on the two terminal studs marked B.SH., and the generator is connected to the testing leads. Other types of hand-ringing

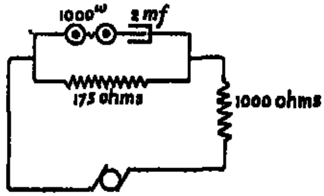


FIG. 64.—Generator Test.

generators have to give a commercial ring on a standard magneto bell when put in series with 40,000 ohms. For this test the upper left-hand switch arm is put on terminal stud marked 40,000 ohms, and the upper right-hand switch arm on B. Smaller resistances for similar purposes are also provided on the set. Magneto bell tests under both the foregoing conditions are provided for on terminals marked G.SH., and 40,000 ohms and G, respectively, the bell being connected to the testing leads. A power-driven generator is generally available for these tests, and is connected as shown in Fig. 63 to all the combination testing sets fitted in any one room. The terminal studs marked BZ on the upper switches are connected to a buzzer and battery, and provide means for proving local circuits of relays, night bell circuits of indicators, etc., by means of the upper leads when the instruments are being tested for working currents on the lower switches. If desired, a detector can be used for this purpose by putting the upper right-hand switch arm on terminal stud D. The terminal studs marked CB and CBS are connected to model common battery and common battery signalling exchanges, and consequently provide means for carrying out functional tests—ring, speak, and clear—of telephone sets connected to the leads of the two upper switches, set at CB or CBS as required. Speech transmission tests of the receiver and transmitter are not, as a rule, made on these combination testing sets, but on the circuits shown in the previous chapter. In testing bell sets a 46 mile artificial cable can be inserted at the model exchanges to prove the induction coil. The terminal studs marked M are connected to a pair of leads which join all the sets in the room in multiple, and afford facilities for working between any two testing tables where this is found to be desirable. The set is very compact, convenient, and economical, and its successful operation is quickly learned by the testing officers. It is largely used in the testing of repaired apparatus, for which purpose it was originally introduced.

Over 100 different types of terminal telephones have been brought into use by the Post Office at various times to meet special requirements. To facilitate identification the types arranged for fixing to a wall are given consecutive odd numbers, and those for use on a desk or table consecutive even numbers.

Table Telephone No. 2 (Fig. 65) and Bell set No. 1 is the most popular terminal telephone, and it is purchased in very large numbers. Generally speaking, the transmitter and receiver are purchased separately, and are tested independently, as described in the previous chapter, the transmitter being supplied to the maker of the pedestal and fitted by him. The receiver is fitted when the telephone is installed. The functional test of the pedestal is made on a combination testing set connected to a model Exchange. In addition to ascertaining that the switch hook provides for automatically changing the connections, so as to afford ringing, speaking, and clearing facilities, it is necessary to check that the connections and disconnections are made in the

correct order, otherwise a very loud and disagreeable click will be heard in the receiver if the subscriber operates the switch hook to attract the attention of the Exchange operator. When the functional test is being made the operator at the model Exchange calls attention to the fact if any click is received when the switch hook is operated.

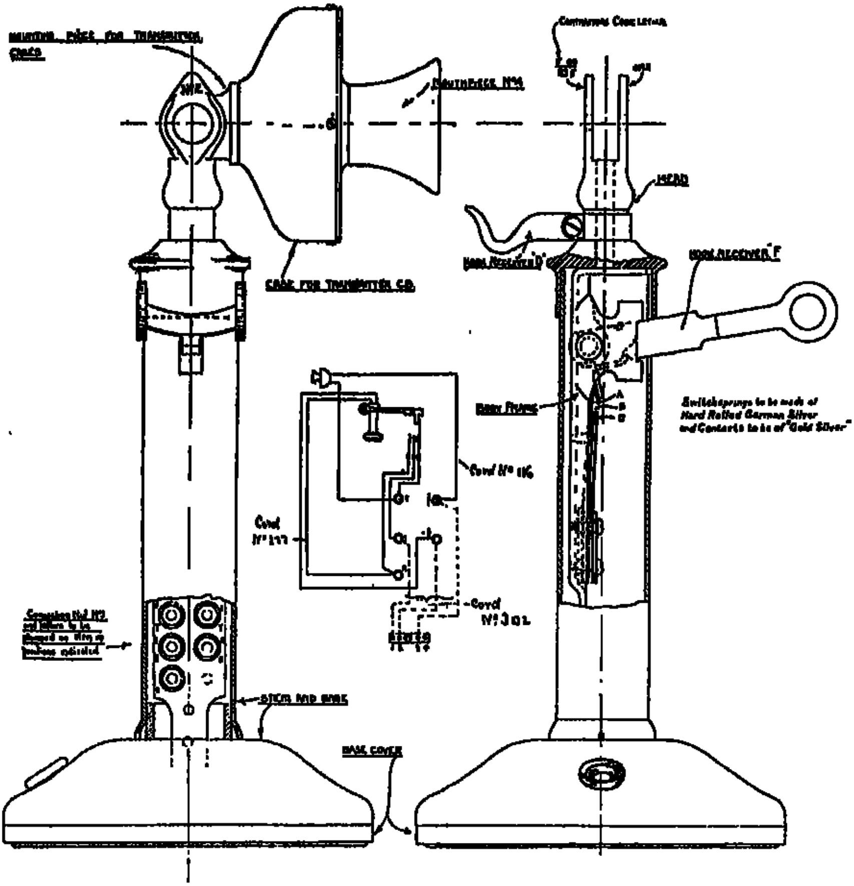


FIG. 65.—Telephone No. 2. Mark 235.

It is necessary to test to ensure that no two parts are in electrical contact that should be separate or insulated, and this test is usually referred to as an insulation test, although no measurement of the actual resistance is made. For the insulation test a power-driven ringing generator in series with a magneto bell is used, the bell being adjusted to ring through any resistance less than 100,000 ohms. Every telephone is given a functional test before approval.

The procedure is as follows :—

The ends of the conductors on the receiver cord are first connected together, and

(*a*) With the switch hook up, terminal 1 is tested against the frame.

(*b*) With the switch hook down, terminal 1 is tested against 2 and 3, and then 2 against 3. The bell rings if there is a short circuit, or if the insulation resistance is less than 100,000 ohms. The actual value of the insulation resistance is not required, and this test is sufficient and generally adopted for proving the insulation of the ordinary wiring of telephones.

(*c*) Join up a Bell receiver and Bell set No. 1 to the telephone No. 2. Ring the model Exchange by lifting the receiver from the hook, speak to Exchange over 30 miles of artificial cable. Speech should be cut off and clear signal should be given to Exchange when switch hook is depressed. Exchange listens and reports if a click is received when the switch hook is slowly depressed and allowed to rise.

(*d*) Press the switch hook upwards and inwards. Exchange reports whether any disconnection is caused by the pressure.

The test (*d*) is necessary to ensure that there is not sufficient movement of the switch hook to operate the switch springs. Trouble from this cause has occasionally been found due to loose fitting.

Test of Bell Set No. 1 (Fig. 66).—These Bell sets are generally purchased separately from the pedestal telephones. The tests are made on a combination testing set.

Resistance.—(*a*) Primary of induction coil 17 ohms between terminals L_1 and TR.

(*b*) Secondary of induction coil 26 ohms between terminal R and terminal 3 of induction coil.

(*c*) Secondary of induction coil and bell coils in series, 1026 ohms, between terminals R and E.

Direction of Windings of Induction Coil.—A small pocket compass is placed on the induction coil, and one lead from a 2-volt battery is connected to terminals L_1 and R. The other lead from the battery is applied to terminals 2 and 3 of the induction coil in turn. If the induction coil is correctly wound and connected, the compass needle will be deflected in the same direction in each case. If the induction coil is wrongly wound and connected, a loss of about 8 miles of standard cable will result, and it is therefore important to check the windings by this test. The windings should be in the same direction, so that their effect on the core is to induce the same polarity.

Insulation Resistance.—Using testing leads with combination testing set generator and bell in series test :—

(*a*) E against frame of bell in Bell set No. 1.

(*b*) E against L_1, i.e. winding against winding of induction coil.

Bell and Condenser Test.—Join up the Bell set No. 1 to a telephone No. 2. Using leads and testing set generator test terminal E

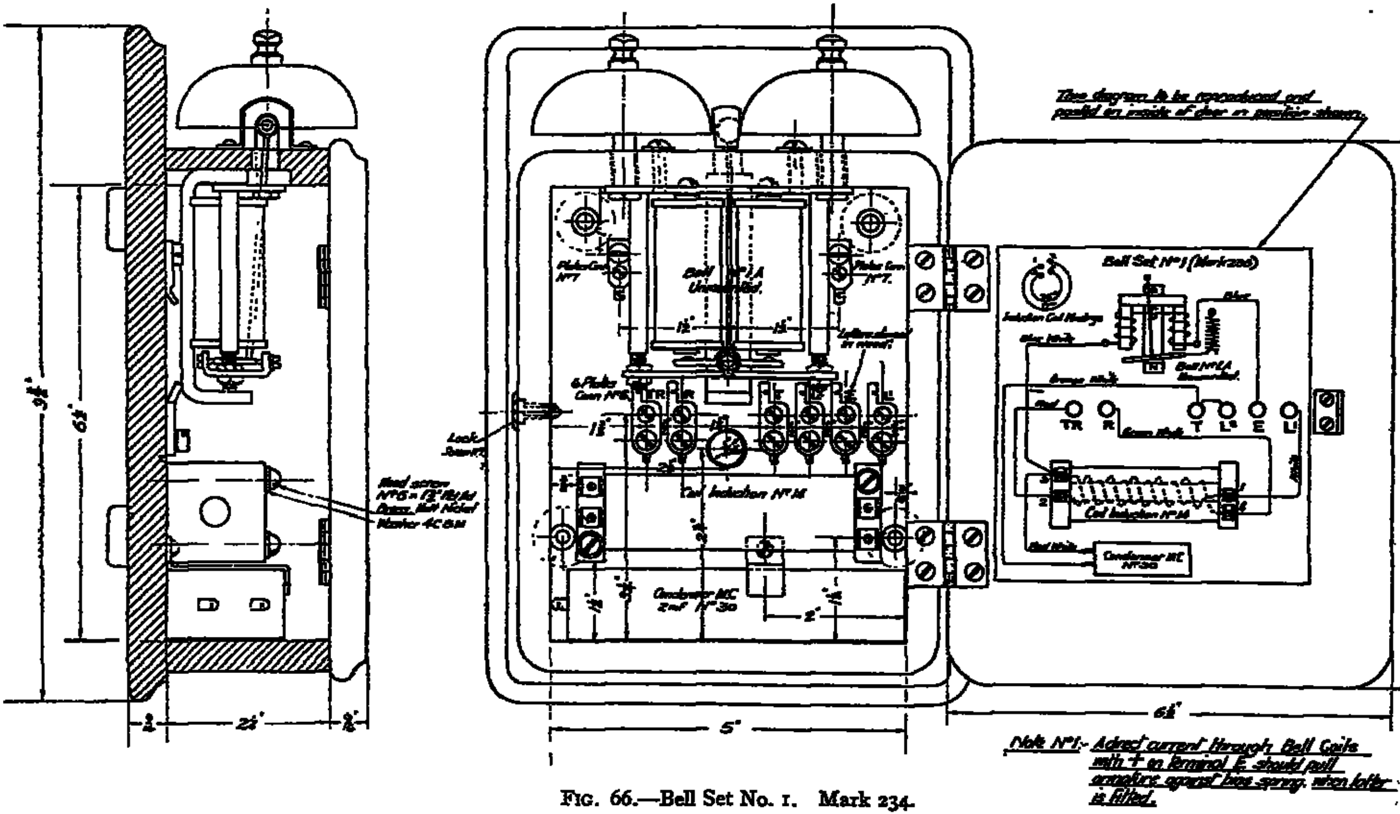


FIG. 66.—Bell Set No. 1. Mark 234.

against R with the switch hook depressed. The Bell set No. 1 bell should give a good loud ring.

Short Circuit Testing Set Condenser.—Apply standard bell test, that is, ring in on E and L_2 with 1000 ohms in series with testing set generator, and 175 ohms shunted across E and L_2. The Bell set No. 1 bell should ring. After taking the testing lead off L_2, let the switch hook rise. The telephone bell should give an audible click, due to the condenser discharge.

Test of Induction Coil.—Speak to model Exchange over 30 miles of artificial cable, and compare the speech received with that received when a standardised Bell set No. 1 is used. The volume of speech in the two cases should be equal. A contact between adjacent turns will cut down the volume of sound by 2 or 3 miles of standard cable, and a contact between adjacent layers by 7 or 8 miles.

Telephone No. 1.—The transmitter, receiver, and condenser are tested separately before assembly. The following tests are made with the combination testing set.

(1) *Resistance.*—The receiver is not connected.

(*a*) Primary of induction coil, 17 ohms, between A and TR (Fig. 67).

(*b*) Secondary of induction coil, 26 ohms, between R and right-hand terminal of bell coil.

(*c*) Bell coil + secondary of induction coil, 1026 ohms, between R and E.

Join up receiver and remove strap from E.

(2) *Direction of Windings of Induction Coil.*—Switch hook down. A small pocket compass is placed on the induction coil, and one lead from a 2-volt battery is connected to terminals A and R. The other lead from the battery is applied to terminals 2 and 3 of the induction coil in turn. If the induction coil is correctly wound and connected, the compass needle will be deflected in the same direction in each case.

(3) *Insulation Resistance.*—Using testing set leads and generator and bell in series

(*a*) With switch hook up test E against bell frame and switch hook.

(*b*) With switch hook down test A against R.

(*c*) With switch hook up or down test B against transmitter case.

Reconnect strap to E.

(4) *Bell and Condenser Test.*—Switch hook down. Using leads with testing set generator, test terminal A against R. The telephone bell should give a good loud ring. Short circuit testing set condenser. Apply standard bell test, that is, ring in on A and B with 1000 ohms in series with testing set generator and 175 ohms across A and B. The telephone bell should ring. After taking the lead off terminal B let the switch hook rise. The telephone bell should give an audible click due to the condenser discharge.

(5) *Testing of Induction Coil and Switch Hook Connections.*—Connect the telephone to the model Exchange connections on combination testing set. Ring model Exchange by lifting receiver off the

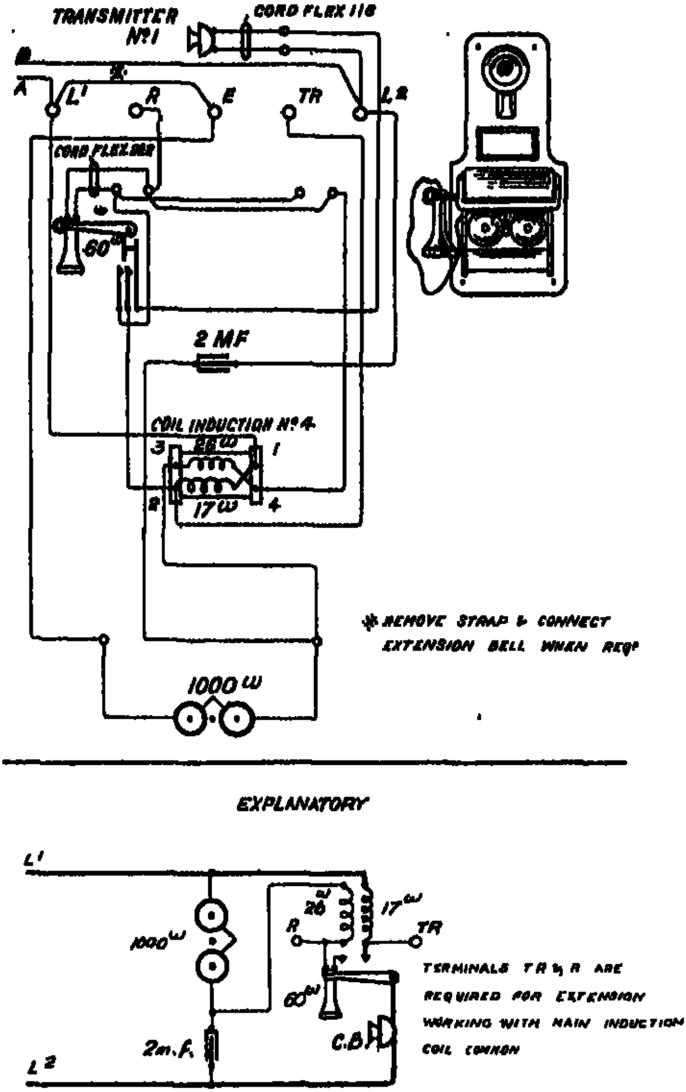


FIG. 67.—Telephone No. 1.

switch hook, speak through 30 miles of artificial cable to model Exchange over telephone, and then over a standard telephone No. 1. The Exchange operator compares the volume of speech received

which should be equal in the two cases. Listen on the receiver while Exchange speaks; depress switch hook while speech is being received, and note whether speech is cut off, and whether any audible click is heard. Press the switch hook upwards and inwards. Exchange reports whether any disconnection is caused by the pressure. Short circuit the extra receiver terminals with the switch hook up, and see that this cuts off the reply from the Exchange.

Wall Telephone No. 3 and **Wall Telephone No. 11** are similar, except that the latter is fitted with a magneto generator. No. 3 is used on a common battery signalling circuit, and No. 11 on a magneto circuit. A wiring diagram of No. 3 is shown in Fig. 68. When required, a coin collecting box is connected to terminals marked CB. Terminal EB is connected to earth. Terminal G is used on telephone No. 11 only and is then connected to EB. The lines are connected to terminals A, B. The wiring diagram of telephone No. 11 is shown in Fig. 69. It will be seen that the coils of the magneto bell are joined in series in No. 11 and in parallel in No. 3. In the latter telephone continuity should be proved between terminals A and No. 1 on generator terminal plate, G and 2, and B and 3, which is readily done by means of a dry cell in circuit with a low resistance buzzer. The receiver and transmitter are usually purchased and tested separately.

(1) *Resistance Tests.*—Between terminals A and EB, switch hook down 1000 ohms, bell coils in series for telephone No. 11, and 250 ohms for telephone No. 3.

Telephone No. 11.—Between terminals A and B, switch hook down and generator cut-out operated, 400 ohms, winding of armature.

Between terminals A and B, switch hook up and receiver conductors short circuited, 25 ohms, secondary winding of induction coil.

Between terminals + and −, switch hook up terminals CB and CB short circuited, 1 ohm, primary winding of induction coil.

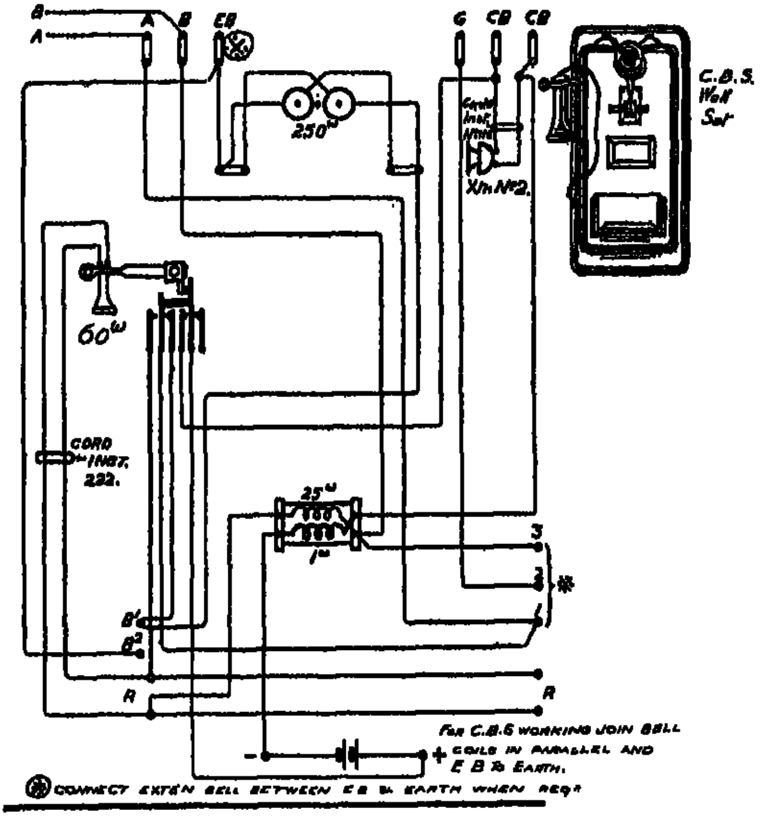
(2) *Bell Tests.*—Telephone No. 3 with hand generator in series with 15,000 ohms, switch hook down, between terminals A and EB, bell should give a good ring.

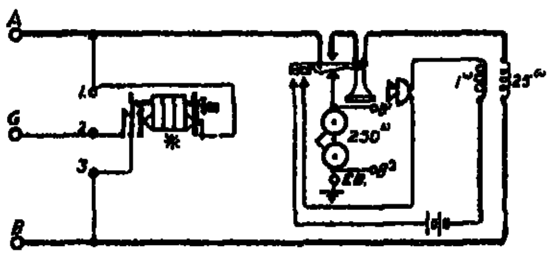
Telephone No. 11.—Ring on terminals A and B with testing set generator. The telephone No. 11 bell should give a loud ring, which should be stopped when the switch hook rises, and also when the generator handle is turned. With standard generator test connections joined to A and B, ring with the telephone generator. The testing set bell should ring, but not the telephone bell.

(3) *Insulation Test.*—

(*a*) Switch hook down. Short circuit receiver cord and transmitter connection plates.

Test terminal A against (1) frame of bell.
" " " (2) switch hook.
" " " (3) terminal B.
" " " (4) +
" " " (5) −
Test terminal B against + and −.
" + against −.



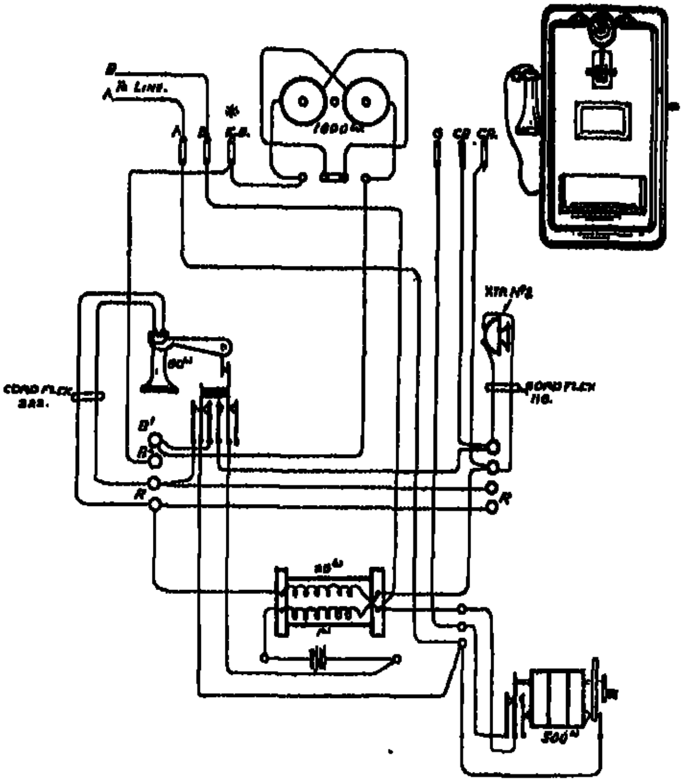


*GENERATOR ONLY FITTED WHEN REQUIRED FOR MAGNETO WORKING

FIG. 68.—Telephone No. 3. Mark 238.

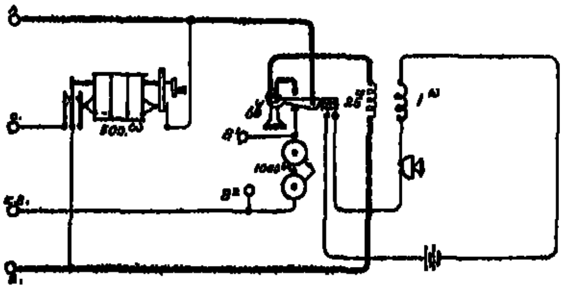
(*b*) Switch hook up. Disconnect receiver cord and transmitter connection plates.

Test A against B, EB, and + and −.
,, B ,, EB, + and −.
,, EB ,, + and −.
,, + ,, −.



* Connect extension bell between terminal EB and earth when required for C.B.S. system or between terminals G and EB for magneto system.

Explanatory.



For C.B.S. working connect EB to earth and join bell coils in parallel; for magneto working connect EB to generator terminal G.

Fig. 69.—Telephone No. 11. Mark 238.

(4) *Induction Coil Test.*—Switch hook up. Connect a 2-volt battery to the battery terminals of the telephone. Connect up a Bell receiver and a primary battery (inset) transmitter. Speak over 30 miles of artificial cable to model Exchange, and then by means of a two-way switch; arrange to speak over a standard telephone of the same type. Exchange reports whether volume of speech in the two cases is equal. The switch hook when depressed should cut off the speech. Short circuit on the extra receiver terminals should cut off the speech from the Exchange.

The foregoing tests indicate the general methods followed in testing terminal telephones, and may be taken as representative of all types. All telephones are examined mechanically for workmanship and finish. The principal points needing attention are dealt with in Chapter XII.

Condensers, Metal Cased.—Until a few years ago telephone and telegraph condensers were made from sheets of pure tinfoil and high-grade tissue paper. It was necessary to dry the paper very thoroughly and to prevent moisture being absorbed during the course of manufacture. Two sheets of paper were used between each pair of tinfoils, the tinfoils being cut so that a lug was left on the left and right sides of adjacent tinfoils. These lugs became the two terminals of the condenser. After assembly of the required number of sheets, depending upon the capacity of the condenser, the condenser was thoroughly dried and then placed in a bath of hot paraffin wax, allowed to soak, and subsequently subjected to pressure in a press. In recent years this method of manufacture has been abandoned for telephone condensers in favour of a type invented by Mr. G. F. Mansbridge, of the Post Office. A full description of this condenser will be found in Mr. G. F. Mansbridge's paper read before the Institution of Electrical Engineers, London, in May, 1908 (vol. xli., p. 535). The Mansbridge condenser possesses many novel features, but only a brief description can be given here. Instead of using separate sheets of tinfoil and paper, what is known in the trade as a "foiled" paper is employed. This consists of a very high-grade paper, on one side of which is spread metallic tin, and made to adhere to the paper with a suitable sizing material. The metallic surface is subsequently burnished. Foiled paper can be made in long lengths, and advantage of this fact is taken to manufacture condensers by winding up into the form of a roll two long strips of foiled paper, two strips of tissue paper separating each two foiled papers, i.e. six strips in all. Connecting lugs of annealed copper foil about 1 mil thick and $\frac{3}{8}$ inch wide are afterwards fitted. The condenser is subsequently treated with paraffin wax and pressed to the required degree. Mansbridge condensers possess the remarkable property of sealing up after a small electrical breakdown, due to grit or defects in the papers. In the paper quoted above Mr. Mansbridge says: "This automatic sealing is brought about in the following way. Owing to the extreme thinness of the conducting film, the small quantity of heat generated at the point of short circuit by the sudden discharge of the condenser through that point

is sufficient to cause the film of metal immediately surrounding the point of breakdown to be fused into minute globules. The segregation of these globules from each other and from the surrounding metallised surfaces effectually isolates the point of breakdown, and the defect is instantaneously sealed up. So rapid, indeed, is this effect, that if a pin is stuck into an insulated charged condenser so as to produce short circuits between the foiled papers, the short circuits seal up without fully discharging the condenser, and a dozen or more of such short circuits may be created one after the other before the condenser becomes fully discharged." Advantage of this property is taken in the course of manufacture to free the materials of any defective places by subjecting the materials to an electrical pressure test, and consequently the finished condenser is practically proof against electrical breakdown. The Post Office Specification for condensers of this type stipulates that the capacity shall be not more than 10 per cent. higher or lower than the nominal value, the insulation resistance in megohm-microfarads not less than 300, and the electrification not less than 20 per cent. The capacity is measured by comparing the discharge deflection given on a reflecting galvanometer by the condenser under test with that obtained from a standard mica condenser. The procedure is as follows. The standard mica condenser, the exact capacity of which is known to three figures, is charged by means of a battery of about 30 volts for 10 seconds. The condenser is then discharged through the galvanometer and the throw or discharge deflection noted. The condenser to be tested is then charged by means of the same battery, and then discharged through the galvanometer and the deflection noted. The capacities are directly proportional to the discharge deflections for practical purposes. Where a large number of condensers of the same kind have to be tested, it is convenient to adjust the battery power so that the deflections read directly in capacity values. For example, let the known value of the standard mica condenser be 0·339 microfarads. By varying the voltage applied to the condenser, the throw obtained on discharging the condenser through the galvanometer can be made exactly 339 divisions, so that 1000 divisions would correspond to 1 microfarad. Hence a 2 microfarad condenser would give a throw of 2000 divisions, or what is equivalent to it, 200 divisions when the galvanometer is shunted with $\frac{1}{10}$ shunt. The galvanometer should give the same throw from the same condenser on both sides of zero, which can be readily checked by reversing the battery connections and repeating the discharge test. This proves that the scale is parallel with the mirror, and that the galvanometer throws are sufficiently accurate for practical purposes. Fig. 70 is a diagram showing the connections for a capacity test.

Insulation Test.—Before this is made it is necessary to ascertain the insulation constant of the galvanometer. The galvanometer is shunted with a high value shunt, and the deflection given through a high resistance—usually 1 megohm—is ascertained. Suppose that with the 5000th shunt a deflection of 240 divisions is obtained through 1 megohm, then it is assumed that the galvanometer would

give a deflection of one division through 240 × 5000 = 1,200,000 megohms. This number, which happens in this case to be 1,200,000 is usually referred to as the insulation constant. To measure the insulation resistance of the condenser the same battery is employed, and usually consists of 300 volts. A stop watch is used to time the test, because the reading obtained on the galvanometer 60 seconds after applying the 300-volt battery is used in calculating the insulation resistance, and the reading obtained on the galvanometer 120 seconds after applying the 300-volt battery is used in calculating the electrification per cent. Before the 300-volt battery is applied to the condenser the short circuit key of the galvanometer is operated so that the initial charge into the condenser will not pass through the galvanometer but through the short circuit key. With an insulation constant of the value quoted above, it is necessary when testing a condenser of 2 microfarads to use a tenth shunt, in order that the deflection of the galvanometer may be brought on to the scale a few seconds after the battery is applied. The deflection of the galvanometer, if the condenser is a good one, should decrease, but at a rate which gets slower and slower. The following table shows how the deflection decreases with increase of time :—

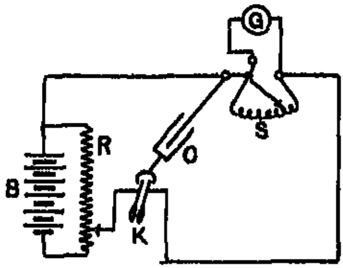


Fig. 70.—Diagram of Connections for Capacity Test.

G Reflecting galvanometer.
S Universal shunt.
C Condenser under test.
K Charge and discharge key.
B Battery of about 30 volts.
R High resistance (adjustable).

Time in Seconds.	Divisions Deflection.	Time in Seconds.	Divisions Deflection.
10	1200	100	210
20	500	110	200
30	400	120	195
40	340	130	190
50	290	140	180
60	250	150	175
70	240	160	170
80	230	170	165
90	220	180	160

If these deflections and times are plotted on square paper, they will be found to fall on a smooth curve of the rectangular hyperbola type. It will be seen from the table that the deflection at 60 seconds after applying the battery was 250 divisions, since the galvanometer gives only one division deflection through 1,200,000 megohms, the deflection 250 divisions corresponds to a resistance of

$$\frac{1200000}{250} = 4800 \text{ megohms}$$

for the complete condenser, which happened to be of 2 microfarads, and the result for 1 microfarad would therefore be 9600 megohms. This is a very good result, as the specified minimum is 300 megohms. It will also be seen from the table that the deflection at 120 seconds was 195 divisions. The electrification per cent., therefore, is

$$\frac{(250 - 195)100}{250} = 22.$$

A minimum of 20 per cent. is specified.

The insulation resistance between either of the outside soldering tags and the metal case should not be less than 300 megohms. A megger can be used for checking the insulation between the tags and the metal case. It is important to prevent, as far as possible, moist air from getting into the metal case, because moisture causes the apparent capacity to increase and the insulation resistance to decrease very markedly. The following is an extract from the Post Office Specification for metal-cased condensers: "The condenser plates to be tightly fitted in the metal case, and the top to be hermetically sealed before the metal top is put on. The sealing composition must not be brittle or so soft that it will flow at a temperature of 75° F., and it must adhere firmly to the tinned iron case. The ebonite strip carrying the tags to be securely riveted to the metal cap, and the latter to fit well and to be firmly soldered to the body of the case at both ends. The use of any soldering flux other than resin is prohibited."

Condensers, Wooden Cased.—These are almost exclusively used for telegraph purposes, and the method of testing is the same as for metal-cased condensers, but the specified requirements are more stringent. The capacity of all plates of 1 microfarad and above must be within 5 per cent. of the nominal value, but for smaller plates 10 per cent. is allowed. In the case of signalling condensers, the two halves of the condenser must not show a difference greater than 0·25 microfarad. The insulation resistance of large telegraph condensers consisting of several sections is taken on the condenser as a whole, and not on the separate sections. The battery is of 400 volts, and the insulation resistance in megohms multiplied by the capacity in microfarads must not be less than 2000. The minimum electrification is 20 per cent. At the end of the second minute the battery is reversed and the test continued for a third minute, during which time the deflection must be free from unsteadiness, and there must be no tendency to increase. Trouble is sometimes experienced in consequence of surface leakage over the bases of keys, etc. It is found convenient in practice to enclose as much of the apparatus as possible in a case somewhat similar in shape to a roll-top desk, and to keep a couple of electric lamps alight in the case while testing is in progress. These lamps effectively overcome leakage troubles by keeping the air in the case warm and dry.

CHAPTER XII

WORKMANSHIP AND FINISH

It has already been mentioned that terminal telephones are purchased by the Post Office in very large numbers, and it may be said that the competition amongst manufacturers for Post Office contracts is very keen. It is obvious, therefore, that in these circumstances the same standard of workmanship and finish should be reached by all manufacturers, and this result is secured by providing detailed working drawings, specifications, and patterns. The following notes on workmanship and finish will give a fair indication of the points which are regularly checked during the examination of the supplies.

All metal work should be free from flaws, blow-holes, and other defects. Particular attention is paid to *screws*, which must be of the specified size, well screwed home, a good fit, and without undue shake in the tapped holes. They should be tried for overturning, that is to say, that they cannot be turned indefinitely without tightening up. Too much force must not be used in trying screws for overturning, especially where they are used in materials like ebonite, otherwise the defect will be produced in the examination. Terminal and connection screws should be flat under the head, and should not have sharp or burred edges that would be likely to damage a connecting wire. The head of the countersunk screw, when used in metal parts, should be flush with the surface or slightly below it. When screws are used to fix the bottom on to a table instrument, this requirement of sinking them slightly below the surface is additionally important, or damage to the subscriber's table is likely to result. Terminal nuts should screw on easily and without undue shake. All electrical contact surfaces should be clean, and must not be lacquered. Wire joints are carefully examined to ascertain whether they are clean, neatly made, and soldered satisfactorily. Occasionally joints are soldered imperfectly, the solder failing to unite the two ends of the twisted wires or other connections, with the result that the joint is said to be "dry." These joints cause considerable trouble if they escape detection, because they tend to set up imperfect contacts, which may result in undesirable noises on the line. The flux used for soldering is always resin. Zinc chloride, killed spirits, and similar fluxes which are liable to set up corrosion are prohibited on instrument work. The wiring

should be in accordance with the specified colour scheme and coated with shellac varnish when used on switchboards, etc. The insulating covering should always be left as close as practicable to the point of connection, and there should be no loose or frayed ends. Wiring and cabling should be left long enough to enable any necessary adjustments to be made, especially where the wiring is attached to a hinged door or cover. All instruments that will be fitted with a cover should be tested with the cover in position, to ensure that the fitting of the cover is satisfactory, and that the cover does not impair the efficiency of the instrument. Bells fitted with metal covers are especially liable to defects from this cause. All bobbins should be wound with wire of the correct size, so that the bobbin is fairly filled, and it is inadvisable to have an undue amount of packing. When the inside ends of the coils of indicators, relays, etc., are twisted and soldered together, the joints should be covered with a neat tube of braiding to prevent any liability of contacts. All holes through which instrument cords are threaded should have well-rounded edges so as to prevent, as far as possible, the cord being damaged by undue friction. The loops, bases of forks, and ends of cords should be neatly bound and free from loose ends. Where an additional end of braiding is fitted, this braiding should be tied so that it will take any pull or strain that may be put on the cord, and thus prevent the conductors from being damaged. When there are two or more conductors in a cord, each conductor should be covered with cotton of a distinguishing colour. The inside of telephone receivers should be clean and quite free from loose wax, metallic particles from the grinding process, and dust. Ear-pieces should fit accurately, and be interchangeable with the pattern or gauge. The inside surface of the ear-piece should be smooth, and the diaphragm seating quite flat. The height of the diaphragm seating above the inside surface should be in strict agreement with the drawing. The diaphragm should be truly circular and flat. The edges of the diaphragm should be free from burrs, and should be clamped satisfactorily by the ear-piece seating. Occasionally the diaphragm buckles slightly when the ear-piece is screwed home, and in this event it may even bed on the pole-pieces. By tapping the diaphragm with the finger or clicking the diaphragm by pressing the finger on the edge of the ear-piece central hole and stepping down sharply on the diaphragm, it will be found that the sound given off will be a hollow one if the diaphragm is free, or a dull one if the diaphragm is touching the pole-pieces. The remedy is to change the diaphragm or the earpiece. All bell armatures or the cores of the electromagnet should be fitted with brass stop-pins to break the iron circuit and thus prevent sticking. Bell hammers should be adjusted so that when they are at rest they do not touch the gong. Steady pins should fit tightly into their seatings. Permanent magnets should be free from hardening cracks and flaws. Locks should operate smoothly, be well fitted, and when of a standard type they should be tried with a standard key. Where pivoted

armatures are used they should be in a central position with regard to the cores of the electromagnet, and the pivots should not have an undue amount of shake. Hammer stems are preferably screwed to the head and to the armature, and not riveted or soldered. The stems should be central in the slot in the case, and have sufficient clearance to function properly. The switch hooks should operate reliably with a receiver of the standard weight, viz., 13 ounces, and the edges of the hook where the receiver rests should be well rounded. A diagram of the connections is usually fitted inside the case of wall telephones, and in the inside of the case of Bell sets. The arm supporting the transmitter on wall telephones should be free to move smoothly over the full range, but tight enough to remain in any position desired. Where connections are made to spiral springs on the hinges of wood cases, continuity should be proved and the connections should be soldered. The screws fixing the induction coil are usually fitted with spring washers, to ensure a good connection. The inside frame of table telephones (pedestal type) should be a clean stamping, rigidly fixed to the cap, and the metal bush at the bottom of the frame should be well riveted to prevent it from turning when the base plate fixing screw is screwed home. The pillar tube should fit tightly in the cap, and the slot for the switch hook should not be excessively wide or deep. An ebonite bush should be fitted in the hole in the base, through which the cord passes. Steady pins should be fitted between the base and pillar tube to prevent turning. All parts should be firmly fixed in the case. Where hand generators are fitted, they should work smoothly and without undue noise. The pip and plate contacts on springs should be tightly fitted, and the pip should bed in the middle of the plate and not on the extreme edge. The edges of the driving crank of the generator should be well rounded, and the screw in the handle should be sunk well below the surface. Where the bell is liable to be joined, both in series and in parallel, the connection plates should be accurately spaced to enable the desired change of connections to be easily made. The foregoing notes refer principally to terminal telephones; other notes will be included in a subsequent chapter dealing with Exchange apparatus. With regard to finish, the pattern is taken as the standard, and it in all cases represents the quality of work and the degree of finish to be supplied. In the case of walnut and other woods that have a dark-coloured heartwood and a light-coloured sapwood, the general appearance of the article being examined is borne in mind, and as a rule sapwood is not approved. The grain of the wood should run in the same direction as that of the wood in the pattern, which is always arranged to give maximum strength against any likely stresses to which it may be subjected, as in writing desks for wall telephones, etc. Ebonite should never be polished by treatment with spirit polishes or lacquers. It is generally left dull from the cutter when fitted in strips or with the natural polish it takes when moulded. When cut with a sharp knife, ebonite that is tough and elastic will give a fairly long thin

shaving that curls readily, but brittle ebonite will not give a shaving—it breaks short. For most telephone purposes a tough ebonite is indispensable. Ebonite when rubbed vigorously on a coat sleeve gives off an odour characteristic of india-rubber, and will attract small pieces of paper, black celluloid gives off an odour of camphor, and will not attract small pieces of paper. Celluloid is not used by the Post Office for telephone parts, but some authorities allow the mouthpieces of hand-telephones to be made of this material. All ebonite parts should be free from cracks, grease, and metal dust. Switch springs are usually made of nickel silver, sometimes called "German silver," and should be hard-rolled and elastic, so as to give a good pressure on the contacts, which are made of a gold-silver alloy (90 per cent. silver, 10 per cent. gold). Diaphragms are made of stalloy, a steel containing about 3 per cent. of silicon. Formerly they were made of ferrotype, similar to that used in the old days by photographers. Vegetable fibres can be distinguished from animal fibres by burning them. Cotton, etc., burns readily, continues to glow when the flame is extinguished, and to emit a pungent odour. It leaves behind a small quantity of ash which is soft to the touch and light-coloured. Silk, wool, etc., do not burn so readily as cotton, give off a characteristic odour, do not glow when the flame is extinguished, and leave a black ash which, when crumbled between the fingers, is found to be gritty and to resemble charcoal. Tussah silk is obtained from China, and is the product of the wild Tussur or forest silkworm. It is light brown in colour. Silk obtained from cultivated sources, such as that obtained from Italy, is either raw or spun. The fibres of raw silk are in long lengths (filature), reeled direct from the cocoons. Spun silk is obtained by spinning the short and waste fibres. Botany Genappe is a smooth worsted yarn spun from a fine-fibred wool, and is used sometimes for the outer braiding of some telephone cords. Hemp, flax, and jute can be best identified by means of the microscope, but jute is weaker in torsion than the other two. If a few fibres of jute be pinched between the thumb and first finger of both hands placed close together, and then given a sharp twist, the fibres of jute will break, but hemp and flax will not.

Iron and steel must always be coated to protect them from the oxidising influence of the air. The coating should be free from missed places and blemishes, otherwise oxidation will begin at these points and spread under the coating. Ordinary galvanising is generally confined to materials for use in line construction. For telephone parts, either sherardising, zinc plating, coslettising, or nickel-plating is employed.

Sherardising consists in heating the article to be sherardised in an iron barrel to a temperature of about 250° C. whilst the articles are surrounded by zinc dust. The coating of zinc obtained by this process is very even and smooth, but not quite so bright as that produced by the galvanising process. This process can be applied to Whitworth and similar screw threads, but

the ordinary galvanising process cannot, as it would fill up the threads and render them useless. Zinc plating is done by an electrolytic process, and in appearance the surface produced is somewhat similar to a sherardised surface.

Coslettising consists in treating the iron or steel with dilute phosphoric acid at boiling temperature, and concentrating the solution by evaporation. At the end of the process the articles treated have a coating of phosphate of iron, which is black and of a matt or dull finish. The surface is subsequently treated with a good black lacquer. Shutters of indicators, magnets, etc., are often treated by this process, and the results obtained are quite satisfactory.

Nickel-plating is mostly applied to copper, brass, and other alloys of copper, but it can be satisfactorily applied to iron and steel, if they have previously been plated with copper. The nickel is electrolytically deposited, and the surface, when desired, is subsequently polished in a polishing lathe by means of felt, calico, and swansdown mops. The nickelled surface should be even and free from discolorations, missed places, and blisters.

Tinning.—Copper wire, which is subsequently to be covered with india-rubber, requires to be tinned to prevent chemical action between the copper and the rubber. The wire is cleaned with dilute acid passed through a series of felt wipers, a suitable flux, and then through a bath of molten tin, the superfluous tin being removed by wipers. The tinned surface should be bright and free from discoloration and missed places. Interior fittings are generally chemically tinned, which leaves them in appearance similar to unpolished nickelled work. The process consists of boiling the cleaned articles in a copper pan in a solution of cream of tartar containing granulated pure tin, rinsing in clean boiling water, and drying in warm sawdust. Connection tags are usually coated with solder. The tags are cleaned, dipped into a solution of resin in methylated spirit, and then immersed in molten solder.

Bronzing.—When this process is applied to brass or iron and a copper relief is desired, the metal, after chemical cleaning, is plated with copper. It is then dipped into the bronzing solution, which may be of various composition, 2½ ounces of potassium sulphide plus 2½ ounces of ammonium hydrosulphide in 1 gallon of pure water is the composition of a solution that has given satisfactory results. The article is allowed to remain in the bronzing solution for about half a minute, rinsed in cold and then hot water, and dried in boxwood sawdust. The appearance at this stage is a dull black. Small parts of the black surface are removed with a felt mop rotating at a high speed, and the whole is then polished with a rotating basil leather mop. The polished surface is immediately afterwards lacquered with a good colourless lacquer. There should be no signs of peeling or blistering.

Black Enamel.—This process is applied to the pedestals of table telephones, etc. It consists of dipping the metal into a good enamel

similar to that used for enamelling bicycle tubes, and afterwards heating the enamelled article in an enamelling oven for about two hours. The temperature of the oven is generally about 300° F. The surface should be even and bright, and there should be no tendency for the enamel to chip or crack.

Lacquering.—This process is applied to metals that are liable to tarnish, such as brass, copper, etc. It consists of applying a thin layer of lac to the warmed surface of the metal. The lac is dissolved in alcohol, and the resulting lacquer is applied to the warmed surface of the metal by means of a camel hair brush or mop. If the metal is heated to too high a temperature the spirit in the lacquer is evaporated so rapidly that the lac is left in a patchy and uneven condition, producing an unsatisfactory result. For bronzed and nickel-plated parts a process known as cold lacquering is sometimes employed, and consists of applying to the surface an approved composition known as cold lacquer.

To facilitate identification of types and the collation of data with regard to life of plant, a systematic scheme of marking is adopted by the Post Office whereby the manufacturer's identification letter, the year of supply, the mark number, and the type number are either engraved or stamped on all complete instruments. For example, $\frac{\text{W . 20}}{236}$ No. 1 would be engraved or stamped on a type No. 1 instrument of Mark 236, made by the Western Electric Company in 1920. In general, it may be said that instruments of the same kind and type number always perform the same function, and as regards function, are interchangeable, but for certain purposes it is necessary that they shall be of the same mark number. The mark number indicates the particular design of the instrument, and the starting-point in the mark number is No. 234, that is to say, original or pioneer designs receive this mark No. 234. If the design is subsequently modified in essential details so that it is no longer interchangeable with the original design, although performing the same function, the type number remains unchanged, but the mark number becomes 235. If the design is altered a second time, involving a new mark number, the mark number will become 236, and so on. This enables the Post Office to accept alternative designs from different manufacturers, each manufacturer's design being given, if necessary, a different mark number. Occasionally the manufacturer's code number is adopted as the mark number, but these cases are exceptional. The type number is engraved or stamped on all complete component parts, such as indicators, relays, jacks, keys, plugs, etc., and in some cases the type number furnishes other information with respect to detail. For example, indicators No. 1 D$\frac{2}{5}$—No. 1 is the type number, D refers to the resistance, the numerator indicates the number of indicators mounted, and the denominator the number of indicators each strip will accommodate. Again, Jacks No. 503 A.N.—No. 503 is the type number, and in this series the thousands and hundreds digits

refer to the number of points per jack (in this case five), and the tens and units digits the number of jacks per strip (in this case three); A indicates the gauge of the jack (internal diameter of socket) and N indicates the type of mounting strip upon which it is fitted. The foregoing examples sufficiently indicate the general principle followed in marking apparatus, the marking to be put on the apparatus being supplied to the manufacturer when the contract is placed. It is perhaps unnecessary to say that the marking is carefully checked, especially the first supplies under the contract, as any error in the marking is likely to cause trouble later on. All apparatus that has been examined, tested, and approved is marked with a rubber stamp, as shown in Fig. 71, each inspector having a number allotted

FIG. 71.

to him, so that any defective material that is inadvertently approved by the inspector can be traced to the inspector responsible, the practice being of considerable educational value.

CHAPTER XIII

EXCHANGE APPARATUS

All Exchange apparatus is tested at the manufacturer's works ar approved before being despatched to the Exchange. It is importa to provide Exchanges with apparatus that will require the minimu of attention after installation, or the maintenance cost of the Exchan will be excessive. A somewhat elaborate system of examinati and testing is therefore in the long run economical. Where the tes are numerous and the item is to be used on every subscriber's lin it is necessary to provide special testing appliances wherever pra ticable to expedite the testing. Especially is this the case wi relays, which are three times as numerous in some large exchang as the subscriber's lines, and practically each relay must be subject to a series of tests to determine its reliability in operation. No le than four separate current tests are applied to some relays, as w be seen from the schedule of tests which is given later. It is nece sary, for instance, to insure that a line relay will not be operat by a small leakage current such as may arise, due to low but norm insulation of the line, and it is the practice, therefore, after applyi the working current to a relay to reduce the current to a specifi releasing value to ascertain that the relay will function satisfactor under the worst normal conditions likely to be met with in practi Further, a line relay on a very short subscriber's line may have operate with a heavy current from the common battery, and it necessary, therefore, to ensure that it will be released when t current is reduced to its specified value. Similarly, for cut- relays, in addition to the minimum working current, it is necessa to apply a minimum retaining current to ensure that the armatu will not be released when the relay is shunted by the subscribe meter or an operator's relay, etc., and that it will release afte heavy current such as is used in registering a call. The seve currents that have to be applied to each relay have been accurat determined under practical conditions, and they are always specifi Fig. 72 is a diagram and Fig. 73 a photograph of a relay testing which enables the testing officer to apply the specified currents turn to each relay by means of keys instead of changing connecti by hand. It will be seen from the figure that rheostats are fittec the several circuits, so that they can be set at the desired values give the specified currents, which are indicated on the milliamme

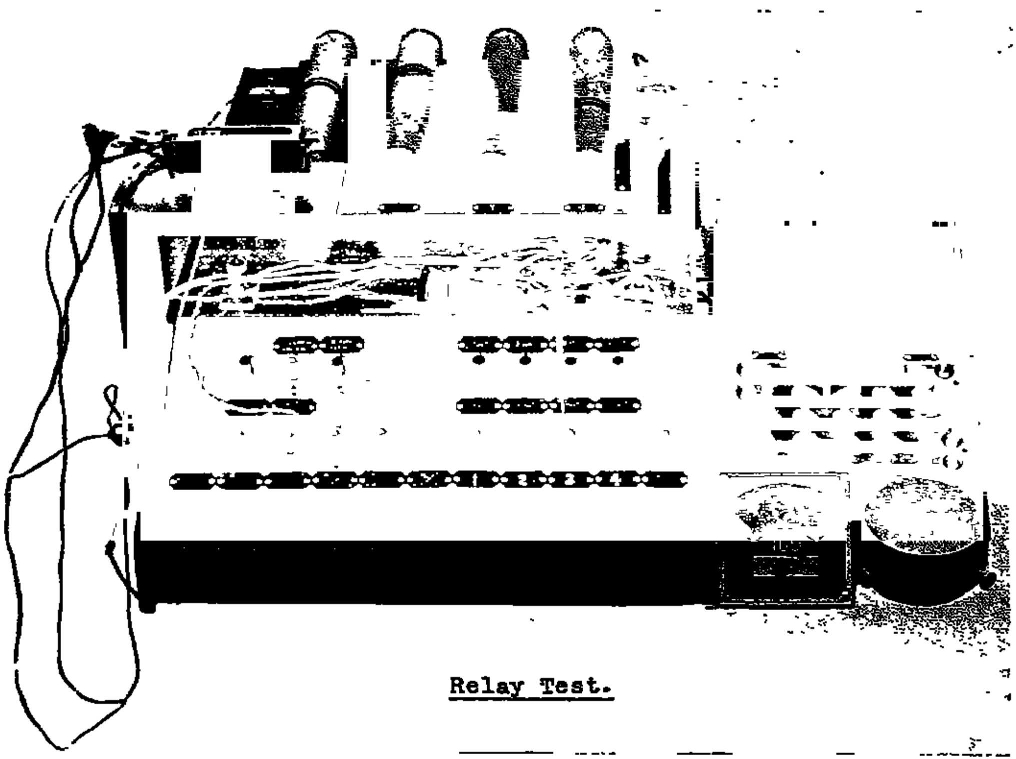


Fig. 73.—Relay Testing Set.

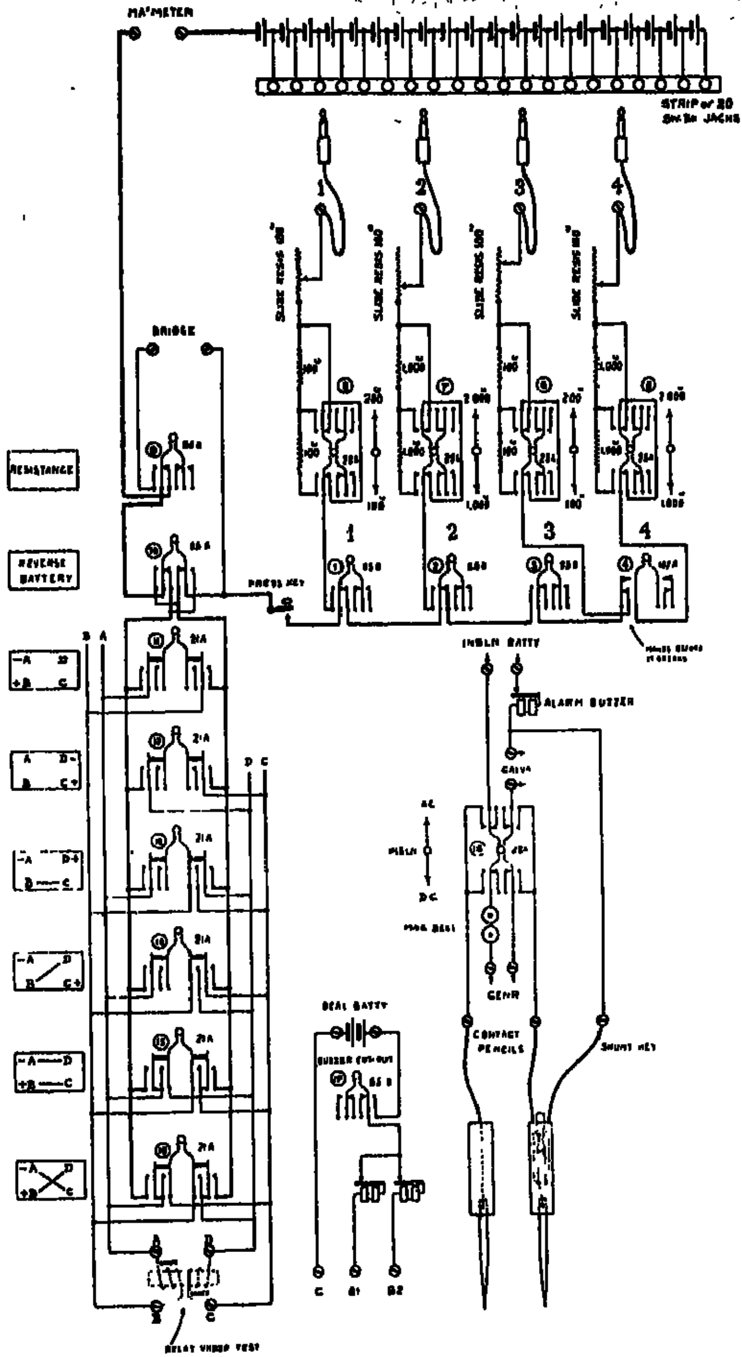


Fig. 72.—Diagram of Relay Testing Set.

The relay is connected to the test leads $\frac{AD}{BC}$ and the local terminals to C, B_1, B_2.

To Measure Resistance.—Operate key 9, bringing in Wheatstone Bridge on ohmmeter or combination testing set, and then operate key 11 to measure resistance of coil AB, restore key 11, operate key 12 to measure resistance of coil CD, restore key 12, operate key 13 to measure resistance of AB and CD in series. Finally, restore keys 12 and 9.

Operating Current.—No. 1 plug is inserted into a battery jack of convenient value for the current required, and keys No. 1 and 14 are operated. Press key is operated and slide resistance in plug circuit No. 1 is adjusted until milliammeter indicates the desired current. Sometimes the operating currents for

(*a*) Coils in parallel;
(*b*) Each coil separately

are specified, the keys to be operated would then be for

Condition (*a*) 1 and 15;
Condition (*b*) 1 and 11; 1 and 12.

Differential Test.—No. 2 plug is inserted into a battery jack of convenient value, and keys 2 and 16 are operated for differential parallel test. Operate press key and adjust slide resistance till milliammeter indicates the desired current. For differential series tests keys 2 and 13 would be operated.

Releasing Current Test.—To release with small current after applying larger current: Coils in parallel. Insert plugs 3 and 4 into battery jacks of convenient values, operate keys 3 and 15. Adjust slide resistance until current desired is indicated on milliammeter.

Operate Key 4.—It will be seen from the figure that operating key 4 has the effect of cutting out plug circuit 3, but without disconnecting the circuit, the long spring of key 4 making before the short one is broken. Adjust slide resistance until current desired is indicated on milliammeter.

Operate Press Key.—Operate key 3 and then key 4 (key 3 remaining operated) relay should respond to key 3, but release with key 4. The local buzzer will cease to work when the armature is released.

The slide resistances remain in their adjusted positions, and the set is now ready for dealing with a large batch expeditiously. It will be noticed that keys 5, 6, 7, and 8 provide facilities for adding additional resistances to the slide resistance when adjusting currents. The arrow heads point in the direction in which the key-handle is moved, which is opposite to that in which the springs are operated, the diagram being arranged for use with the testing set, where the handles are visible but not the springs. The figure also shows an arrangement for taking an insulation test, either with a battery or with a generator and bell in series. The function of the alarm

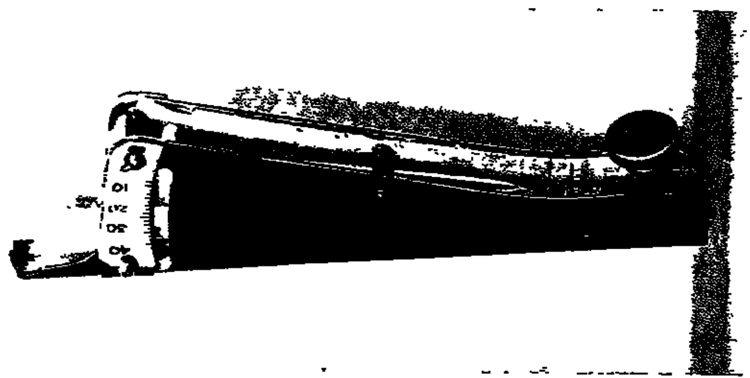


FIG. 74.—Siemen's Relay Contact Pressure Tester.

buzzer is to give warning in the event of there being a short circuit in the winding of the instrument under test, the short circuit key for the galvanometer in the contact pencils protecting the galvanometer against excessive currents.

Having once set the rheostats for a particular type of relay, the whole batch numbering perhaps one or two hundred, or even more, can be tested without further alteration of the testing set. It should be mentioned that when the air gap between the core and the armature is adjustable, this should have been set at its correct value before the relays are presented for test. The spring pressure at the contacts, and the clearance when the contacts are open, are generally specified. A convenient device for measuring the spring pressure is made by Messrs. Siemens, and is illustrated in Fig. 74. It consists of a bent lever, very light in weight, which is attached to one end of a nickel silver strip, the other end of the strip being screwed to one side of a pivoted rocker. The other side of the rocker is fitted with an adjusting screw, which enables the rocker to apply varying degrees of tension to the nickel silver spring. There is a graduated scale on the side of the case, and an indicator which is set by means of the adjusting screw at the point desired. The bent lever lifts at the weight indicated on the scale, and, consequently, if the pressure on the relay contacts is satisfactory, the relay spring lifts the bent lever at the specified pressure. It is a quick, convenient and reliable device. The clearance is determined by means of a series of small gauge strips of steel plate of different thickness, the plates of the series increasing in thickness by 1 mil steps. The foregoing are the usual routine tests applied to bulk supplies. If a more detailed knowledge of the operation of the relay is required, the following procedure is adopted, the tests being made in the order shown :—

(1) Resistance of windings.

(2) Insulation resistance.

(3) Demagnetisation of core. An alternating current is applied to the windings of the relay, and resistance is added until the current flowing is of negligible value. A ringing generator which gives a frequency of about sixteen periods per second is generally used for the purpose.

(4) Operating current. As most relays in modern Exchanges are of the non-polarised type, the relay should be tested for operating current in both directions, that is to say, the current should be reversed after testing in one direction.

(5) Measure pressure on make contacts while operating current is passing through the winding, and measure clearance between contacts.

(6) Test for retaining current by adding resistance to cut down current from operating value to retaining value. The relay should not be disconnected while the current is being reduced from the operating to the retaining value. The test is applied in both directions.

(7) Special tests, if any.

(8) Apply saturation current for the specified time.

(9) Releasing current. Cut down saturation current by adding resistance until releasing current is reached and without disconnecting the relay.

(10) Measure pressure on break contacts while releasing current is passing through the winding and clearance between make contacts.

(11) Apply non-operating current in the same direction of flow as the saturation current in test 8.

(12) The heating current or voltage should be applied to the windings for the time specified (usually one or two hours), and the relay winding should remain undamaged, due to the heat developed.

(13) After the winding has cooled to normal temperature (60° F.) the relay should be tested again under the conditions set forth in tests (1) to (11), and if satisfactory demagnetised before placing in stock.

As a general rule, in the routine tests it is not necessary to demagnetise the relays. There are about 400 different telephone relays used by the Post Office, and the schedule shows the requirements to be met by each.

Except that it is necessary to see that the coil tags are securely fixed in the coil checks and in the right positions, so that it will not be necessary to bend the tags when fitting the relays to the mounting, and that the contacts are clean, there is very little else that requires attention as regards examination in bulk. Where the ends of windings are jointed together the flux used in soldering the joint is powdered resin. Since the wires are of small gauge, anything that would tend to set up corrosion and cause disconnection, such as a flux containing free hydrochloric acid must be avoided. Resin gives only a slightly acid reaction and is the best flux for this purpose. The joint is covered with a fine braiding of silk. When the winding is of very thin wire it is finished off either with a few turns of thicker wire and covered with paper and bookbinder's cloth, or with a close even layer of thicker wire green-silk covered. The latter method is employed when the winding is left visible. The tags should be coated with tin to facilitate the soldering on of the leads. The contacts are usually made of platinum.

TELEPHONE RELAYS.

TABLE OF TESTS.

Note.—S = Series. P = Parallel. N.I. = Non-inductive. E = Each winding separately.

Relay No.	Resistance.	Current. Operating.	Current. Retaining.	Current. Saturation.	Current. Releasing.	Current. Non-operating.	Current. Differential.	Heating Test. Current.	Heating Test. Volts.	Heating Test. Time.	Contact Pressure. Break.	Contact Pressure. Make.	Contact Clearance. Break.	Contact Clearance. Make.	
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
	ohms.	m. a.	m. a.	m. a.	m. a.	m. a.	m. a.	m. a.		mins.	grams.	grams.	mils.	mils.	
1A	50 + 50	12	—	50											
B	100 + 100	9	—	45											
C	200 + 200	6	—	35	Windings in series.						10	10	10	10	—
D	500 + 500	4	—	25											
E	1000 + 1000	3	—	20											
F	6000 + 6000	1	—	3·5											
2A	500 + 500	S4	—	—	—	—	S12	—	—	—	—	—	—	—	—
3A	4000	1·5	—	—	—	—	—	—	—	—	—	—	—	—	—
5A	50 + 50	S6	—	—	—	—	—	—	—	—	—	—	—	—	—
B	100	6	—	—	—	—	—	—	—	—	—	—	—	—	—
C	1000	2	—	—	—	—	—	—	—	—	—	—	—	—	—
D	500 + 500	2	—	—	—	—	—	—	—	—	—	—	—	—	—
6A	5 + 5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B	100 + 100	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C	150 + 150	—	—	—	—	—	—	—	—	—	—	—	—	—	—
D	500 + 500	S4 P9	—	S25 P40	S0 P3	—	S100 P200	—	—	—	4	4	10	10	—
E	1000 + 1000	—	—	—	—	—	—	—	—	—	—	—	—	—	—
F	1800 + 3000	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7A	500 + 500	S4 P9	—	S25 P40	S0 P3	—	S100 P200	—	—	—	4	4	10	10	—

TABLE OF TESTS—*continued*

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
	ohms.	m.a.	m.a.	m.a.	m.a.	m.a.	m.a.	m.a.		mins.	grams.	grams.	mils.	mils.	
B	1000 + 1000	S2·9 P6·4	—	S17 P28	S0 P2·1	—	S70 P140	—	—	—	4	4	10	10	—
D	100 + 100	S9 P21	—	S50 P55	S0 P0·5	—	S220 P440	—	—	—	4	4	10	10	—
8A	60	12	—	—	—	—	—	—	—	—	—	—	—	—	—
9A	30	38	—	—	—	—	—	—	—	—	—	—	—	—	—
10A	60	19	—	270	2·5	—	—	—	28	60	—	1·5	—	20	—
B	100	20	—	140	2·8	—	—	—	28	60	—	1·5	—	20	—
C	50	15	—	280	2·36	—	—	—	28	60	—	1·5	—	20	—
D	20 + 30	P18	—	P455	P3	—	—	P455	—	60	—	1·5	—	20	20ω with 30ω N.I. shunt.
E	200	16	—	75	2·8	—	—	75	—	60	—	1·5	—	20	—
11A	100	15	—	140	2·8	—	—	28	—	60	7	12	10	15	—
B	200	8·5	—	110	1·5	—	—	28	—	60	7	12	10	15	—
C	300	7	—	130	0	—	—	28	—	60	7	12	10	15	—
D	50	15	—	280	2·8	—	—	—	28	60	7	12	10	15	A.C. test also.
12A	83	30	—	—	—	—	—	—	—	—	—	—	—	—	—
B	200	25	—	—	—	—	—	—	—	—	—	—	—	—	—
13A	80	3	—	—	—	—	—	—	—	—	—	—	—	—	—
B	·9	100	—	—	—	—	—	—	—	—	—	—	—	—	—
14A	2000	15	—	—	—	—	—	—	—	—	—	—	—	—	—
15A	100	60	—	—	—	30	—	—	—	—	—	—	—	—	—
B	300	27	—	67	—	—	—	—	—	—	—	—	—	—	—
16A	500	3	—	50	—	—	—	—	—	—	—	—	—	—	—
17A	500 + 500	S1	—		—	—	—	—	—	—	—	—	—	—	—
18A	500 + 500	S2	—	—	—	—	—	—	—	—	—	—	—	—	—
D	500 + 500	S2	—	—	—	—	—	—	—	—	—	—	—	—	—
19A	500 + 500	S3	—	13	—	—	S30	—	—	—	—	—	—	—	—
20A	200 + 200	S12	—	50*	—	—	—	—	—	—	—	—	—	—	* for 30 seconds

21A	12000 + 27	P12	—	—	—	—	—	P160	—	—	—	—	—	—	—
	12000 coil only	1·5	—	2·3	·5	—	—	2·3	—	—	—	—	—	—	—
22A	83·5	57	—	196	—	—	—	120	—	60	20	20	10	10	—
B	180	40	—	120	—	—	—	120	—	60	20	20	10	10	—
C	500	25	—	56	—	—	—	—	28	60	20	20	10	10	—
D	350	29	—	80	—	21	—	—	28	60	20	20	10	10	—
E	250	35	—	100	—	—	—	—	28	60	20	20	10	10	—
F	1000	19·6	—	39	—	—	—	—	28	60	20	20	10	10	—
G	30	73	46	230	—	—	—	230	—	60	20	20	10	10	—
H	240 + 1200	P57	—	P120	0	—	—	—	P28	60	20	20	10	10	A.C. test also.
J	40*	68	—	160	—	—	—	160	—	60	20	20	10	10	* 45ω with 360ω N.I. shunt.
L	160	45	—	188	—	36	—	188	—	60	20	20	10	10	—
M	200	50	—	122	—	40	—	122	—	60	20	20	10	10	—
N	2000	8·9	—	14	—	—	—	28	—	60	20	20	10	10	—
P	100	50	—	120	—	—	—	120	—	60	20	20	10	10	—
23A	30	80	—	—	—	—	—	—	—	—	—	—	—	—	—
12B	1000	12	—	40	0	—	—	—	—	5	—	—	—	—	—
24A	83·5	57	—	196	0	—	—	120	—	60	20	20	10	10	—
B	350	29	—	80	0	21	—	—	30	60	20	20	10	10	—
C	30	73	46	230	0	—	—	230	—	60	20	20	10	10	—
D	45 + 360	P68	—	P160	0	—	—	P160	—	60	20	20	10	10	—
E	180	40	—	120	0	—	—	120	—	60	20	20	10	10	—
F	500	41	—	80	0	—	—	—	39	60	20	20	10	10	—
G	1000	19·6	—	39	0	—	—	28	—	60	20	20	10	10	—
H	2000	8·5	—	13·5	0	—	—	28	—	60	20	20	10	10	—
J	200	45	—	120	0	35	—	25	—	60	20	20	10	10	—
K	240 + 1200	P57	—	P120	0	—	—	—	28	60	20	20	10	10	A.C. test also.
25B	60	20	—	280	2·8	—	—	—	—	—	—	10	—	20	—
26A	75 + 75	E16	—	E200	E1·2	—	—	200	—	60	—	5	—	20	—
B	50 + 50	E20	—	E20	E4	—	—	—	S28	60	—	5	—	20	—
C	500 + 500	E11	E2·9	E44	E1·25	—	—	—	S28	60	—	5	—	10	—

TABLE OF TESTS—*continued.*

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
	ohms.	m. a.	m. a.	m. a.	m. a.	m. a.	m. a.	m. a.		mins.	grams.	grams.	mils.	mils.	
D	250 – 250	E11·9	—	E40	E2·4	—	—	—	S28	60	—	5	—	20	—
28A	200 – 200	E29	—	†E500	0	E25	—	—	28	60	10	10	10	10	Special test also. † For two seconds only.
B	100 – 100	S10	—	S140	S4	SS·5	—	—	28	60	5	10	15	15	—
C	1000 + 1000	S4	—	S11	S·6	—	—	—	22	60	5	5	10	10	—
30A	30	*73	37	1250 for 10 secs	0	—	—	320	—	60	28	—	10	—	* With relay 25A. fitted above on same mounting.
B	40	00	—	160	0	—	—	160	—	60	28	—	10	—	—
31A	12·5	18	—	455	3	—	—	455	—	60	—	10	—	20	—
C	30	Now	relay	147A	—	—	—	—	—	—	—	—	—	—	—
D	0·47	90	—	80	23	—	—	3000	—	60	—	10	—	20	—
E	200	5	—	114	—	—	—	—	25	60	—	10	—	20	—
F	30	30	—	230	—	—	—	230	—	60	—	10	—	20	—
G	300	1	—	—	—	—	—	—	—	—	—	—	—	—	—
H	500	4	—	6	—	—	—	—	—	—	—	10	—	20	—
J	180	12	—	133	1·2	—	—	—	—	—	—	10	—	20	—
K	1	40	—	60	—	—	—	—	—	—	—	10	—	20	—
32A	350	55	—	78	0	—	—	—	—	—	20	20	10	10	—
B	20	109	—	155	0	—	—	—	—	—	20	20	10	10	—
C	30	73	—	300	0	—	—	—	—	—	20	20	10	10	—
D	*45	68	—	160	0	—	—	—	—	—	20	20	10	10	* With 360 ohms N.I. shunt.

36A	500	10	—	—	—	—	—	—	—	—	—	—	—	—	—
37A	{ 250 +	60	—	—	—	—	—	—	28	60	—	—	—	—	—
	30 + 38	P70	—	—	—	—	—	P3000	—	60	—	10	—	20	—
		50 on 30 ohm winding only													
39A	30	22	—	200	2	—	—	—	8	60	—	10	—	20	—
B	250	8	—	110	—	—	—	—	28	60	—	10	—	20	—
C	1·25	80	—	3000	0	—	—	3000	—	60	—	10	—	20	—
D	3·8	50	—	500	4·5	—	—	1100	—	60	—	10	—	20	—
E	500	4	—	50	·1	—	—	—	28	60	—	10	—	20	—
39F	*300	5	—	130 for 10 secs	0	—	—	—	—	—	—	5	—	10	* Within 2·5 per cent.
G	165	9	—	90	·82	—	—	200	—	60	—	10	—	20	—
H	1000	3·7	—	28	·18	—	—	—	28	60	—	5	—	10	—
J	21	17·8	—	450	2·36	—	—	530	—	60	—	10	—	20	—
K	·47	70	—	70	25	—	—	3000	—	60	—	10	—	20	—
L	·1	330	—	1300	30	—	—	1300	—	60	—	5	—	20	—
N	200	5	—	140	0	—	—	—	28	60	—	5	—	10	—
P	1·4	73·5	—	73·5	14·7	—	—	1750	—	60	—	5	—	10	—
Q	80	18	—	350	2·8	—	—	—	28	120	—	10	—	20	—
R	120	10	—	120	1·3	—	—	—	14	60	—	10	—	20	—
AA	200	5·5	—	130	0	—	—	—	28	60	—	20	—	10	A.C. test also.
40A	1	56	—	2240	0	—	—	2240	—	60	—	10	—	20	—
B	·5	80	—	3000	0	—	—	3000	—	60	—	10	—	20	—
C	180	12	—	133	1·2	—	—	—	24	60	—	10	—	20	—
D	30	22	—	200	2	—	—	—	8	60	—	10	—	20	—
E	500	4	—	50	·1	—	—	—	28	60	—	10	—	20	—
F	1000	3·7	—	28	·18	—	—	—	28	60	—	10	—	20	—
H	60	20	—	234	2·8	—	—	—	28	60	—	10	—	20	—
J	300*	5	3·6	130	—	—	—	30	—	60	—	5	—	10	* Within 2·5 per cent.
K	120	10	—	120	1·3	—	—	—	14	60	—	10	—	20	—
L	·1	330	—	1300	30	—	—	1300	—	60	—	5	—	20	—

TABLE OF TESTS—*continued*.

I	II ohms.	III m. a.	IV m. a.	V m. a.	VI m. a.	VII m. a.	VIII m. a.	IX m. a.	X	XI mins.	XII grams.	XIII grams.	XIV mils.	XV mils.	XVI
41A	500 ÷ 500	E9·0 S5·5	— S1·5	E14 S22	E1·5 S0·7	—	—	—	E28	120	—	—	—	—	—
B	75 + 75	SS	—	S100	S·6	—	P120	—	—	—	—	5	—	20	—
C	120 ÷ 520	—	—	—	—	—	—	—	—	—	—	—	—	—	—
D	60 ÷ 60	S20	—	S248	S2·8	—	—	—	—	—	—	—	—	—	—
E	500 ÷ 1000	—	—	—	—	—	—	—	—	—	—	—	—	—	—
F	500 ÷ 240	—	—	—	—	—	—	—	—	—	—	—	—	—	—
H	2000 ÷ 200	5 15	— —	14 140	0 0	— 8	—	—	P24	60	—	10	—	20	—
42A	50	80	—	208	—	—	—	300	—	60	—	20	—	10	—
B	400	78	—	116	—	23	—	—	50	60	—	20	—	10	—
C	1000	20	—	42	8	—	—	—	52	60	—	20	—	10	—
D	500	66·6	—	104	—	—	—	—	52	60	—	20	—	10	—
E	27	83	56	250	—	—	—	320	—	60	—	20	—	10	—
F	350	54	—	80	—	—	—	—	28	60	—	20	—	10	—
G	400	78	—	116	0	23	—	—	—	—	—	20	—	10	—
H	200	80	—	14	0	—	—	—	28	60	—	20	—	10	—
43A	12000 ÷ 27	1·5 P20	— —	2·3 P160	·5 1	— —	— —	2·3 P160	— —	60 60	— —	2 —	— —	10 —	— —
B	2000 ÷ 200	5 15	— 8	14 140	0 0	—	—	—	—	—	—	10	—	20	—
44A	600 ÷ 45	7·5 80	— —	65 170	0 0	— —	— —	65 170	— —	60 60	— —	5 —	— —	10 —	— —
C	600 ÷ 30	7·5 101·6	— —	65 230	0 0	— —	— —	65 230	— —	60 60	— —	5 —	— —	10 —	— —
45A	60 + 60	S20	—	S234	S2·8	—	—	—	28	60	—	10	—	20	One winding N.I.
47A	30	75	—	—	—	63	—	—	—	—	—	—	—	—	—
48A	12000 + 27		Same	as 43A	above										
49A	50 ÷ 50	S15	—	S270	S2	—	—	—	—	—	—	—	—	—	—
50A	83·5	63	—	196	0	—	—	196	—	60	20	20	10	10	—
B	30	78	—	190	0	—	—	190	—	60	20	20	10	10	—

C	100	34	—	34	11	—	—	—	—	—	28	28	10	10	—
D	240 + 1200	P57	—	P120	0	—	—	—	P28	60	20	20	10	10	A.C. test also.
51A	200 + 200	E29	—	†E500	0	E25	—	—	E28	60	10	—	10	—	† For 2 secs. only A.C. test also.
52A	12000 + 27		Same	as 43A	above										
53A	500	66·6	—	104	0	—	—	—	52	60	20	20	10	10	—
54A	100	18	—	234	2·8	—	—	—	28	60	—	1	—	20	—
B	1000	8	—	8	3·5	—	—	—	30	60	—	1	—	20	—
55A	200	36	—	500 for 2 secs. only	0	25	—	—	52	60	—	10	—	10	Special test also.
56A	1900	—	—	53	0	—	—	—	100	60	—	4	—	10	A.C. test.
B	2400	—	—	42	0	—	—	—	100	60	—	4	—	10	
59A	60	25	—	—	—	—	—	—	—	—	—	—	—	—	—
AA	300	5	—	130	0	—	—	—	39	5	—	5	—	10	—
B	180	12·1	—	—	1·2	—	—	—	—	—	—	—	—	—	—
C	6000	·5	—	—	·05	—	—	—	—	—	—	—	—	—	—
D	400	4	—	—	1	—	—	—	—	—	—	—	—	—	—
F	3·8	73·4	—	—	7·3	—	—	—	—	—	—	—	—	—	—
G	80	13	—	—	—	—	—	—	—	—	—	—	—	—	—
H	1	100	—	—	—	—	—	—	—	—	—	—	—	—	—
60A	200 + 200	E21	—	E105	E5	—	—	—	E52	60	—	15	—	10	—
D	1000 + 200	—	—	—	—	—	—	—	—	—	—	—	—	—	—
F	200 + 1000	—	—	—	—	—	—	—	—	—	—	—	—	—	—
L	100 + 100	E70	—	—	—	—	—	—	—	—	—	—	—	—	—
N	75 + 75	E75	—	—	—	—	—	—	—	—	—	—	—	—	—
61A	200 + 200	S21	—	S105	S5	—	—	—	S52	S60	15	—	10	—	—
62A	50	66	49	1040	0	—	—	300	—	60	28	—	10	—	—
B	500	66·6	—	1040	0	—	—	—	52	60	15	—	10	—	—
D	200	36	—	130	5	—	—	—	52	60	15	—	10	—	—
E	27	83	56	1300	0	—	*	1300 250	—	10 60	20	—	10	—	* Should pass both tests.

TABLE OF TESTS—*continued.*

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
	ohms.	m. a.	m. a.	m. a.	m. a.	m. a.	m. a.	m. a.		mins.	grams.	grams.	mils.	mils.	
63A	200 + 200	S28·5	—	S105	S5	—	—	—	E52	60	15	15	10	10	—
B	500	70	55	300	0	—	—	—	52	60	15	15	10	10	—
	+ 50	78	—	104	0	—	—	200	—	60					
C	500 + 500	S18	—	S52	S4·73	—	—	—	E52	60	15	15	10	10	—
64A	400	78	—	116	—	23	—	—	48	60	20	20	10	10	—
B	50	78	54	116	—	—	—	300	—	60	15	15	10	10	—
C	500	66·6	—	104	—	—	—	—	52	60	20	20	10	10	—
D	1000	29	—	48	9·2	16	—	—	52	60	20	20	10	10	—
E	2000	16	—	26	—	—	—	—	44	60	15	15	10	10	—
F	83·5	50	—	110	3	—	—	—	11	60	15	15	10	10	—
G	600 + 1200	P78	—	P116	P0	P23	—	—	P48	60	20	20	10	10	A.C. test also.
65A	400	78	—	116	0	23	—	—	48	60	20	20	10	10	—
B	500	70	—	104	0	—	—	—	52	60	20	20	10	10	—
C	1000	34	—	52	0	—	—	—	52	60	20	20	10	10	—
D	140	75	—	140	0	—	—	140	—	60	20	20	10	10	—
F	*400	78	—	116	0	—	—	—	48	60	20	20	10	10	* 600 with 1200 ohms N.I. shunt.
66B	12000	1·5	—	1·7	·3	—	—	—	—	—	5	5	10	10	—
	+ 50	20	—	30	1·0	—	—	—	—	—	—	—	—	—	—
C	500 – 500	S3·3	—	S48	0	—	—	—	S52	60	5	5	10	10	—
D	100 – 100	S15	—	S87	S2·47	—	—	S87	—	60	5	5	10	10	—
E	10000	1·7	—	5	0	—	—	—	—	—	—	—	—	—	—
	+ 200	P12	—	P116	0	—	—	—	—	—	—	—	—	—	—
67A	5	80	—	200	0	—	—	300	—	60	15	—	10	—	—
B	500	66·6	—	104	0	—	—	—	52	60	15	—	10	—	—
C	2000	14	—	27	0	—	—	—	52	60	20	—	10	—	—
D	107 + 1500	P78	—	P116	0	—	—	P116	—	60	20	—	10	—	A.C. test also.
68A	200 + 200	E36	—	*E500	0	E25.	—	—	E52	60	20	—	10	—	* 2 secs. only. A.C.

69A	0·5 + 0·5	S54	—	S2000	18	—	—	S3000	—	60	—	10	—	16	—
B	500 + 500	†S3·3	†	S48	—	—	—	—	S52	60	—	10	—	10	† A.C. test also.
C	100 + 100	S12·5	—	S87	—	—	—	S87	—	60	—	5	—	10	—
F	1000 + 500	*	*	104	0	—	—	—	52	60	—	5	—	10	* A.C. test.
G	520 + 120	*	*	120	0	—	—	—	14	60	—	5	—	10	
AA	2000 + 200	5 15	— 8	10 25	0 0	—	—	—	—	—	—	5	—	10	—
70A	200	33·3	—	130	5	—	—	—	52	60	—	15	—	10	—
B	10	50	—	120	0	—	—	120	—	60	—	15	—	10	—
C	500	20	—	110	0	—	—	—	52	60	—	15	—	10	—
D	400	25	—	121	0	—	—	—	52	60	—	15	—	10	—
E	50	75	49	300	0	—	—	300	—	60	—	15	—	10	—
F	100	72·8	—	200	0	—	—	—	20	60	—	15	—	10	—
G	1000	29	—	48	9·2	16	—	—	48	60	—	20	—	10	—
H	2000	9	—	13	0	—	—	—	28	60	—	15	—	10	—
J	27	83	56	250	0	—	—	250	—	60	—	15	—	10	—
K	*12	60	—	104	5	—	—	104	—	60	—	15	—	10	* 20 ohms with 30ω N.I. shunt.
L	120	40	—	100	0	—	—	—	14	60	—	30	—	10	—
71A	500	20	—	75	0	—	—	—	40	60	20	—	10	—	—
B	50	75	49	300	0	—	—	300	—	60	20	—	10	—	—
C	200	25	—	130	5	—	—	—	52	60	10	—	10	—	—
D	1000	16	—	28	0	—	—	—	28	60	20	—	10	—	—
E	27	83	56	1300	0	—	*	1300 250	for for	10 60	20	—	10	—	* Should pass both tests.
72A	50	75	49	300	0	—	—	300	—	60	20	20	10	10	—
B	500	67	—	104	0	—	—	—	52	60	20	20	10	10	—
C	200	25	—	130	5	13	—	—	52	60	10	10	10	10	—
D	1000	16	—	28	0	—	—	—	28	60	20	20	10	10	—
E	400	78	—	116	0	23	—	—	48	60	20	20	10	10	—
F	2000	9	—	22	0	—	—	—	44	60	20	20	10	10	—
G	27	83	56	250	0	—	—	250	—	60	20	20	10	10	—
H	400	78	—	116	0	23	—	—	48	60	20	20	10	10	A.C. test also.

TABLE OF TESTS—*continued.*

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
	ohms.	m. a.	m. a.	m. a.	m. a.	m. a.	m. a.	m. a.		mins.	grams.	grams.	mils.	mils.	
73A	500	68	—	104	0	—	—	—	52	60	20	20	10	10	—
B	400	78	—	116	0	23	—	—	48	60	20	20	10	10	—
C	1000	34	—	55	0	—	—	—	52	60	20	20	10	10	—
D	200	50	—	120	0	—	—	—	28	60	20	20	10	10	—
E	83·5	57	—	200	0	43	—	200	—	60	20	20	10	10	—
F	27	83	50	250	0	—	—	300	—	60	20	20	10	10	—
G	50	78	54	116	0	—	—	300	—	60	20	20	10	10	—
H	*600 — 1200	P78	—	P116	0	P23	—	—	P48	60	20	20	10	10	*A.C. tests also.
J	*400 — 1200	P78	—	P116	0	—	—	—	P48	60	20	20	10	10	
74A	200	36	—	500 for 2 secs.	0	25	—	—	52	60	20	—	10	—	Special test also.
75A	500	67	—	104	0	—	—	—	52	60	—	15	—	10	—
B	140	75	—	140	0	—	—	140	—	60	—	15	—	10	—
C	300	78	—	140	0	—	—	—	42	60	—	15	—	10	—
76A	2000	†	—	50	0	—	—	—	†	60	—	10	—	10	† A.C. test.
78A	50	75	49	1040*	0	—	—	300	—	60	15	15	10	10	* For 10 secs.
79A	1000	31	—	48	9·2	16	—	—	48	60	20	20	10	10	—
B	50	75	—	208	—	—	—	210	—	60	20	20	10	10	—
C	500	67	—	104	—	—	—	—	52	60	20	20	10	10	—
D	350	54	—	80	—	—	—	—	28	60	20	20	10	10	—
E	2000	16	—	22	—	—	—	—	52	60	20	20	10	10	—
F	200	33	—	130	5	—	—	—	52	60	20	20	10	10	—
80A	1000 ÷ 1000	S10	—	S26	3·3	—	—	—	S52	60	10	10	10	10	—
B	500 ÷ 500	E38	E9·9	S28	0	—	—	—	S28	60	10	10	10	10	—
81A	200 — 200	S28·5	—	S130	5	—	—	—	E52	60	—	—	—	—	—
82A	20 ÷ 50 ÷ 27	25	—	115	5	—	—	200	—	60	—	10	—	10	—
83A	100	43	—	200	0	—	—	—	20	60	—	10	—	10	—
B	1000	12	—	24	2·6	—	—	—	28	60	—	10	—	10	—
C	27	83	—	250	0	—	—	250	—	60	—	10	—	10	—
84A	200 ÷ 200	S28·5	—	S105	5	—	—	—	E52	60	15	15	10	10	—

85A	200 + 200	S36	—	S130	5	—	—	—	E52	60	15	15	10	10	—
86A	200 + 200	S28·5	—	S105	5	—	—	—	E52	60	15	—	10	—	—
87B	500 + 500	S22·5	—	S52	4·73	—	—	—	E52	120	20	20	10	10	—
88A	1000	19·8	—	28	0	—	—	—	28	60	20	20	10	10	—
B	83	63	—	196	0	—	—	—	17	60	20	20	10	10	—
C	500	25	—	60	0	—	—	—	50	60	20	20	10	10	—
D	140	40	—	140	0	—	—	—	20	60	20	20	10	10	—
E	240 + 1200	P57	—	P120	0	—	—	—	P28	60	20	20	10	10	A.C. test also.
F	30	78	—	300	0	—	—	300	—	60	20	20	10	10	—
89A	1000 + 1000	E5·8	—	—	E1·14	—	—	—	S28	60	5	5	12	20	—
E	100 + 100	E14	—	E208	0	—	—	—	S20	60	5	5	12	20	—
90A	500 + 500	S4	—	—	—	—	—	—	—	—	—	—	—	—	—
91A	200 + 200	E29	—	E500 2 secs.	0	E25	—	—	E28	60	10	—	10	—	Special test also.
92A	50	15	—	210	2·8	—	—	210	—	60	10	10	10	10	—
93A	500	39	—	60	0	—	—	—	—	—	—	—	—	—	—
94A	100 + 100	S30	—	S140	S3	—	—	—	E28	120	15	15	10	10	—
B	500 + 500	E36	E22	E56	5·08	—	—	—	E28	120	20	20	10	10	—
C	50 + 50	E80	—	E480	18	—	—	—	E24	60	56	14	20	12	—
D	250 + 250	E43	—	E43	8	—	—	E43	—	60	56	14	20	12	—
95A	300	6·9	—	17	0	—	—	—	—	—	—	5	—	20	—
B	30	22	—	200	2	—	—	—	8	60	—	10	—	20	—
96A	30	73	37	1250 for 10 secs.	0	—	—	300	—	60	28	—	10	—	—
B	500	18	—	56	0	—	—	—	28	60	28	—	10	—	—
C	100	40	—	80	0	—	—	—	10	60	28	—	10	—	—
97A	2000	9	—	13	0	—	—	—	28	60	20	20	10	10	—
B	200	33	—	130	5	—	—	—	52	60	20	20	10	10	—
C	1000	14	—	52	0	—	—	—	52	60	20	20	10	10	—
D	500	36	24	60	0	—	—	—	28	60	20	20	10	10	—
98A	195	29	—	500 2 secs.	0	25	—	—	28	60	10	—	10	—	A.C. test also.
99F	50	15	—	280	2·8	—	—	—	28	60	7	12	10	10	—
100A	1·025	—	—	—	—	—	—	—	—	—	—	5	—	10	A.C. tests also.

TABLE OF TESTS—*continued*.

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
	ohms.	m. a.	m. a.	m. a.	m. a.	m. a.	m. a.	m. a.		mins.	grams.	grams.	mils.	mils.	
101A	50	·75	55	300	0	—	—	300	—	60	10	10	10	10	—
B	27	83	55	250	0	—	—	250	—	60	10	10	10	10	—
102B	1000	17	—	25	0	—	—	—	28	60	—	10	—	10	—
103B	500	67	—	104	0	—	—	—	52	60	20	20	10	10	—
C	12000	2·5	—	4·3	·79	1·25	—	—	—	—	20	20	10	10	—
104A	400	6	—	35	0	—	—	—	—	—	—	—	—	—	—
105A	1000÷1000	S5·23	—	S8·85	S1·58	—	—	—	E30	60	—	5	—	10	—
B	2500÷2500	S3·3	—	S5·6	1	—	—	—	E30	60	—	5	—	10	—
C	75 + 75	S7	—	—	S·2	—	—	—	E30	60	—	5	—	10	—
106A	1000	14	—	30	0	—	—	30	—	120	—	—	—	—	—
107A	1000	4	—	40	—	—	—	—	40	60	—	5	—	10	—
108A	200	29	—	500 (2 secs.)	0	25	—	—	28	60	10	10	10	10	A.C. tests also.
109A	1000÷1000	E10	—	E24	2	—	24	—	24	60	10	10	10	10	—
113A	500	35	—	60	0	—	—	—	28	60	20	20	10	10	—
B	180	40	—	120	0	—	—	120	—	60	20	20	10	10	—
C	350	29	—	80	0	21	—	—	28	60	20	20	10	10	—
D	30	73	46	230	0	—	—	230	—	60	20	20	10	10	—
E	200	78	—	125	0	—	—	—	25	60	20	20	10	10	—
F	1000	18	—	30	0	—	—	—	28	60	20	20	10	10	—
114A	100 + 100	S20	—	S140	2·8	—	—	—	—	—	—	—	—	—	—
C	500 + 500	E30	E12	E30	3	—	—	—	—	—	—	—	—	—	—
D	250 + 250	E43	—	E175	8	—	—	—	—	—	2 oz.	—	20	12	—
117B	27 + 27	S20	—	S280	2·8	—	—	—	—	—	—	—	—	—	—
119A	†	25* 40*	— —	25* 100*	0* 0*	—	—	100	—	60	5	—	10	—	† 20ω with 30ω N.I. shunt.
120A	250 + 250	P50	—	P80	—	—	—	P112	—	60	25	25	10	10	—
121B	16000 + 400	2·1 22	—	3·1 125	·5 3·6	—	—	—	P52 —	60 —	5	5	10	10	—
122A	500	25	—	60	0	—	—	—	28	60	20	20	10	10	—
B	140	40	—	140	0	—	—	—	20	60	20	20	10	10	—

* Relay may be readjusted for these tests

123A	1000	12	—	28	2·6	—	—	—	30	60	—	5	—	10	—
124A	500	25	—	52	0	—	—	—	—	—	—	5	—	10	—
125A	1000 + 1000	E10	—	E24	2	—	—	—	24	60	—	10	—	10	—
126B	{ 100	70	} —	—	—	—	—	—	—	—	20	20	10	10	—
	+ 350	24													
127A	50	15	—	280	2·8	—	—	—	28	60	—	10	—	10	—
128A	40	68	—	160	0	—	—	160	—	60	20	20	10	10	—
B	2000	7	—	13	0	—	—	—	26	60	20	20	16	16	—
C	200	25	—	70	0	—	—	—	14	60	20	20	16	16	—
129A	200	7	—	133	0	—	—	—	25	60	—	15	—	12	—
B	1·5	80	—	3000	0	—	—	3000	—	60	—	15	—	16	—
C	1000	4	—	50	0	—	—	—	40	60	—	10	—	16	—
130A	2000	7·5	—	13	0	—	—	—	26	60	20	20	16	16	—
131A	{ 50	*110	—	*460	0	—	—	—	†28	60	20	20	15	15	* 50ω winding. † On 50ω winding in series with 10 ohms.
	+ 200	S37	S20	S108	—	—	—	—	—	—	—	—	—	—	
137A	500 + 500	E36	S11	S28	S2·54	—	—	—	E28	120	20	20	10	10	—
138A	1000 + 240	—	—	—	—	—	—	—	—	—	—	—	—	—	—
139A	1000	15	—	31	0	—	—	—	30	60	20	20	10	10	—
140A	{ 30	50	—	130	0	—	—	—	5*	60	20	20	5	5	—
	+ 900	—	10	33	0	—	—	—	30*	60	—	—	—	—	—
									*Simultaneously						
141A	500 + 500	S15	—	S60	0	7	—	—	30	60	—	20	—	5	One winding N.I.
142A	{ 2 +	39	45	250	39	—	—	—	—	—	15	15	10	10	—
	300 + 600	S18	—	—	—	—	—	—	—	—	—	—	—	—	—
143A	150	15	—	130	5	—	—	—	45	60	10	10	16	16	} A.C. test also.
B	50	60	50	300	0	24	—	300	—	60	20	20	10	10	
C	100 + 100	P60	P50	P120	0	P24	—	120	—	60	20	20	10	10	
144A	200	15	—	130	5	—	—	130	—	60	15	—	15	—	—
145A	{ 1000 + 1000 }	S7	—	S14	2	—	—	—	30	60	—	20	—	10	—

TABLE OF TESTS—*continued.*

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
	ohms.	m. a.	m. a.	m. a.	m. a.	m. a.	m. a.	m. a.		mins.	grams.	grams.	mils.	mils.	
146A	200	29	—	500 (2 secs. only)	0	25	—	—	28	60	10	10	10	10	A.C. test also.
147A	30	12	—	12	3	—	—	300	—	60	20	20	20	20	—
148A	200	15	—	130	5	—	—	—	52	60	—	15	—	10	Do.
B	50	60	—	300	0	24	—	300	—	60	—	20	—	10	—
C	100	15	—	105	5	—	—	—	40	60	—	10	—	10	—
D	350	12	—	105	2	—	—	—	45	60	—	10	—	10	—
E	500 + 1100	P12	—	P105	0	—	—	—	P45	60	—	10	—	10	Do.
F	100 + 100	P60	P50	P300	0	P24	—	P300	—	60	—	20	—	10	
150A	750 + 500	S5·5	—	—	S3	—	—	—	—	—	20	20	10	10	—
151A	200	13	—	60	2·5	—	—	—	—	—	15	15	10	10	—
B	50	18	—	280	2·8	—	—	—	—	—	10	10	12	12	—
152A	200	13	—	60	2·5	—	—	—	—	—	15	15	10	10	—
153A	2000 + 400	—	—	P11	1·5	—	—	—	P35	60	—	5	—	10	2000 Inductive. 400 non-inductive.
154A	1900	7	—	50	0	—	—	—	—	—	—	4	—	10	A.C. test also.
155A	500 + 500	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B	500 + 250	—	—	—	—	—	—	—	—	—	—	—	—	—	—
156A	1·5	54	—	2000	0	—	—	2500	—	60	10	10	16	16	—
157A	50 + 500	E75	—	E110	0	—	—	E110	—	60	—	—	—	—	—
158A	500 + 500	—	—	—	S63	—	—	—	S30	60	10	10	10	10	Special test also.
161A	200	16	—	240	5	—	—	—	52	60	14	20	15	12	—
162A	500	40	—	78	0	37	—	—	39	60	—	—	—	—	—
163A	50	20	—	280	2·8	—	—	280	—	60	10	10	16	16	—
164A	50	20	—	280	2·8	—	—	280	—	60	10	—	10	—	A.C. test also.
165A	300	22	—	—	—	—	—	60	—	60	10	10	10	10	—
166A	50	20	—	280	2·8	—	—	—	28	60	—	10	—	16	—

167A	200	15	—	—	—	—	—	—	—	—	—	—	—	—	—
168A	10	75*	37*	—	—	—	—	—	—	—	—	—	—	—	* 10 ohm winding.
	+ 300	S26	—	—	—	S8	—	—	—	—	15	15	10	10	
169A	30	75	25	320	—	—	—	320	—	60	15	15	12	12	—
	+ 500	15	—	50	0	—	—	—	—	—					
170A	200	13	—	60	2·5	—	—	—	—	—	15	—	10	—	—
172A	500	10	—	30	2·5	5	—	30	—	60	15	15	15	10	—
1000A	280	180	—	180	—	—	—	—	50	180	—	17	—	12	—
1003A	1300	47	20	—	—	—	—	—	—	—	—	—	—	—	—
	+ 12·5	102	—	—	—	—	—	—	—	—	—	—	—	—	—
1005A	2000	7	—	24	·5	—	—	—	24	60	10	10	10	10	—
B	1300	12·5	5·0	12·5	4·5	8	—	—	—	—	80	40	20	10	—
1006A	250 + 250	S13	—	S96	5·2	—	—	S96	—	60	20	20	10	10	—
NT 12	250	40	—	—	8	—	—	—	—	—	—	—	—	—	—
„ 13	500	32	—	—	10	—	—	—	—	—	—	—	—	—	—
„ 16	500	7	—	95	·8	—	—	95	—	—	—	—	—	10	—
	+ 20	45	—	416	3	—	—	416							
„ 19	60	20	—	200	2·8	—	—	200	—	60	—	10	—	20	—
	+ 30	73	—	1250	0	—	—	320	—	60	28	—	10	—	—
„ 20	250	8	—	—	1	—	—	—	—	—	—	—	—	—	—
	+ 250	34	—	—	9	—	—	—	—	—	—	—	—	—	—
„ 21	45	6	—	380	24	—	—	—	—	—	2 oz.	—	20	—	—
	+ 250	8·5	—	150	·5	—	—	—	—	—	—	—	—	10	—
	+ 20	50	—	400	5	—	—	—	—	—	—	—	—	10	—
„ 24	100	12	—	250	3	—	—	250	—	—	—	—	—	20	—
„ 29	83·5	63	—	260	17	—	—	260	—	—	2 oz.	2 oz.	20	20	—
„ 38	1000	12	—	—	3	—	—	—	—	—	—	—	—	—	—
„ 39	1000	5	—	—	1	—	—	—	—	—	—	—	—	—	—
„ 45	500	7	—	—	1	—	—	—	—	—	—	—	—	—	—
„ 48	12000	1	—	—	·5		—	—	—	—	—	—	—	—	—
	+ 27	14	—	—	1	—	—	—	—	—	—	—	—	—	—
„ 49	12000	1	—	—	·5	—	—	—	—	—	—	—	—	—	—
	+ 110	8	—	—	2	—	—	—	—	—	—	—	—	—	—
„ 1001	—	See	Relay	N.T.	No. 21	above									
„ 1002	250	8	—	150	75	—	—	150	—	60	—	—	—	20	—
	+ 45	66	—	230	24	—	—	380	—	60	42	—	20	—	* —

Indicators.—As it is necessary to apply to some indicators during the process of testing three or four currents of different value, it is found convenient occasionally to use the relay testing set for the purpose. The following schedule gives the tests of representative types of indicators. The resistance of the coils is regarded as satisfactory if it falls within 5 per cent. of the nominal value.

No.	Special Feature.	Special Fittings if any).	Resistance, Ohms.	Operating Currents, Milliamperes.
1C	Non-polarised drop type with circular shutter. Continuous ringing.	Armature and shutter locals.	50 + 50	32, each coil separatel 11·5 coils in series. 30, differential.
1D	Do. Not continuous ringing.	Armature locals only.	100	11·5.
1E	Do. Continuous ringing.	Armature and shutter locals.	100	11·5.
1G	Do.	Do.	500 + 500	10, each coil separatel 50, differential.
1J	Do.	Do.	1000	5.
2A	Polarised drop.	Shutter locals.	1000	3.
3A	Permanent current system. Subscribers' circuit.	Armature locals.	1000	3.
4A	Self-restoring tubular drop, non-polarised.	Iron jacket and 3 tags.	50 + 50 + 450	22, 50 + 50 coils serie 100, differential. 12, 450 coil.
4B	Do.	Do. 4 tags.	500 + 500 + 50	5, 500 + 500 coil [series 60, 50 coil.
4C	Do.	Do. 3 tags.	500 + 500 + 450	5, 500 + 500 coils [series 10, 450 coil.
4D	Do.	——	1000 + 450	5, 1000 coil. 20, 450 coil.
5A	Non-polarised visual drum armature. Unsheathed for line circuits.	Shutter locals.	500 + 500	8, each coil separately 40, non-sticking in either direction. 100, differential.
5C	Do. Iron or copper sheathed for cord circuits.	Do.	Do.	Do.
22A	Self-restoring similar to 4A.	Iron sheathed.	(*a*) 600 + 45 and (*b*) 1000 + 45	8, 600 coil. 40, 45 coil. 5, 1000 coil. 35, 45 coil.
22B	Do.	Do.	1000 + 100	5, 1000 coil. 35, 45 coil.
100A	Tubular drop, non-polarised.	Iron sheathed shutter locals.	500 + 500	6 coils in series 50 differential
200A	Armature pivoted on core end. Non-polarised drop.	Iron check to front of coil bobbin.	300 + 300	10 coils in series.
200B	Do.	Do.	500 + 500	6 coils in series.
300A	Tubular drop. Non-polarised.	Iron sheath.	1000	12, in either directio[n] after 40 for 1 minute also hand generat[or] with 2 mf. condens[er] and 2000 ohms [in] series.

SCHEDULE—*continued.*

No.	Special Feature.	Special Fittings (if any).	Resistance, Ohms.	Operating Currents, Milliamperes.
400A	Doll's-eye or eyeball signals.	U-shaped iron core extension.	80	20, non-sticking 130.
400AA	Do.	Do.	500	9, „ 40.
400C	Do.	Do.	1000	7·5, „ 30.
400D	Do.	Do.	8	75, „ 250.
400E	Do.	Do.	500	9, „ 40.
400F	Do.	Do.	5000	3, „ 10.
400G	Do.	Do.	300	12, releasing 1.
400H	Do.	Do.	50	24, non-sticking 140.
400J	Do.	Do.	900	7·5 „ 30.
400K	Do.	Do.	1000	7·5, „ 30.
400L	Do.	Do.	3500	4·5, „ 18.
500A	Do	Do.	100 + 100	30, single coil. 120, non-sticking
500B	Do.	Do.	1000 + 1000	10, non-sticking (each coil). 40, differential.
500C	Do.	Do	50	24, non-sticking 140.
500D	Do.	Do.	200 + 200	20, single coil. 5, releasing.
600A	Circular disc signals for keyboards (sometimes called "sixpenny").	Red disc showing through glass disc when operated only. Iron sheath.	50 + 100 (N.I.)	30, coils in parallel. 4, releasing.
600B	Do.	Do.	50	24, non-sticking 140.
600C	Do.	Do.	33	25, saturation 100.
800A	Self-restoring	Grid.	450	13.
900A	Drum armature revolving (small).	Armature locals.	1000	8, non-sticking 40.
1000A	Do. (Large.)	Do.	75 + 150 (N.I.)	40, in parallel. 480, saturation.
1000B	Do.	Do.	4000	3·5, saturation 6.
1100A	Similar to 600A.	Grid.	33	30, releasing 9.
1200A	Drum armature revolving. Copper sheathed.	——	1000 + 1000	10, each coil separately. 40, differential in series.
1300A	Do.	——	1000 + 1000	10, saturation 30. 30 differential in series.
1400A	Non-polarised drop. Line signal magneto system.	Shutter locals.	50 + 50	25, coils in series; also to operate with Ericsson 500 ohm 4-magnet generator shunted with 35 ohms. 170, saturation, and also by direct generator.
1800A	Tubular drop. Non-polarised. Sheathed.	Armature and shutter in front of electro-magnet, shutter locals.	1000	8, after a current of 40 continuously for 1 minute. Also 75-volt ringing generator with 2 mf. condenser and 2000 ohms in series.
1900A	Non-polarised drop.	Shutter locals.	500 + 500	12, after 40 in series for 1 minute.

SCHEDULE—*continued.*

No.	Special Feature.	Special Fittings (if any).	Resistance, Ohms.	Operating Currents, Milliamperes.
2000A	Tubular non-polarised drop.	Shutter locals.	1000	10, in either direction; also with 75-volt ringing generator with 2 mf. condenser and 2000 ohms in series.
2200	Do.	Four connecting tabs pass through holes in armature (occupies smaller space than Indicator 100A, but otherwise similar).	500 + 500	6. 50, differential.
N.T. 4	Non-polarised drop.	Three tags. Shutter locals.	50 + 50	25, non-sticking 170.
N.T. 10	Do. Sheathed.	——	1000	6, „ 51.
N.T. 11	Do.	——	500 + 500	6, „ 51.
N.T. 12	Do.	——	100	25, „ 170.
N.T. 1001	——	——	1000	6.
N.T. 1002	——	——	500 + 500	12 coils in series.

Jacks, Plugs, and Cords.—Probably more troubles in Exchange maintenance are traceable to faulty jacks, plugs, and cords than to any other cause, and this is not perhaps surprising when it is remembered under what conditions these important items are used and the requirements they have to meet. Extreme care, therefore, should be exercised in examining them. It is usual to speak of the diameter of the socket as the gauge of the jack, and to allot to each gauge an identifying letter. The sockets are tested with "Go" and "Not go" steel plug gauges. The following table gives the essential details :—

Gauge of Jack.	Diameter of Socket Mils.		Diameter of Plug Gauge Mils.	
	Minimum.	Maximum.	Go.	Not Go.
A	249·5	251	249·25	251·25
B	251·5	252·75	251·25	253
C	208	209·5	207·75	209·75
D	251·25	252·5	251	252·75
E	227·25	228·75	227	229
F	227·25	228·75	227	229

It will be noticed that the diameter of the "Go" gauge is only ¼ mil less than the minimum socket, and that the "Not go" gauge is only ¼ mil larger than the maximum socket. Since it is more convenient to replace the plugs than a strip of jacks, it is preferable

to arrange for the wear to take place on the plug rather than on the socket of the jack, and, accordingly, while soft yellow metal—brass—is used for making the plugs, a harder metal, sometimes a special alloy, is used for the sockets. The best possible finish is called for on both the interior of the sockets and the surface of the plugs, which should be dead smooth and free from tool marks or other irregularities and corrugations. The outer end of the socket should be rounded or bell-shaped to facilitate easy entry of the plug. The ebonite strip in which the sockets of the jacks are fitted should be square and smooth, but not polished, and should be free from cracks, which sometimes develop during drilling operations. The heads of countersunk screws should be flush with or slightly sunk below the surface, and there should be no projections such as points of screws, etc., which would be likely to prevent the jack strips from being closely assembled. When the strips are drilled and recessed for number plates a gauge is used to check these particulars. The switch springs should be of hard-rolled nickel silver stamped from sheet metal so that the length of the spring coincides with the direction of rolling. The springs should be free from cracks, especially at the bends, where contact is made with the plug, and they should be given a set sufficient to ensure that a pull of not less than 1½ lbs., or more than 4 lbs., will be required to withdraw a standard plug when the strip is arranged so that the pull on the plug is along the axis of the plug. The tag ends of the springs should be tinned for about $\frac{3}{16}$ inch to facilitate the soldering of connections, and the holes or slots left clear of solder so that the connection wires can be readily inserted. The pip and plate contacts on the springs should be of gold-silver alloy (90 per cent. silver, 10 per cent. gold), securely riveted to the springs and the pip bedded approximately in the middle of the plate. All jacks and jack strips are marked with a type number to identify the different kinds. Instrument jacks for operator's or subscriber's telephones are numbered 1, 2, 3, etc. Switchboard jack units are given numbers and suffix letters, such as 300A, 300B, 1000A, etc., the letter signifying the gauge of the sockets, and the hundred and thousand digits the number of points for soldering connections. Switchboard jacks on jack mountings are given numbers with two suffix letters, the hundred and thousand digits and the first suffix letter signifying the unit jack used, the ten and unit digits the number of units on the jack mounting, and the second suffix letter the type of jack mounting. The table on following page gives the dimensions of the steel ring gauges for the different types of plugs.

It will be noticed that the hole in the "Go" gauge is of the same diameter as the minimum socket given in the previous table, while the hole in the "Not go" gauge is 2½ mils smaller in diameter. It is advisable to make the ring gauges thick enough to take care of the straightness of the plug. The first requisite of a plug is that it should function satisfactorily when inserted in the jack in any

position, and to ensure this the profile should be symmetrical about the axis of the plug. A profile gauge is used.

Bent tips and bent plugs generally should not be brought into service, because they are liable to make bad contacts with the springs, causing faint speech. Further, it is important that the interior of the plug should be quite free from loose particles of metallic dust. It is an interesting fact that an alternating voltage of 100 r.m.s. volts will detect short circuits in plugs that appear to be quite satisfactory when tested with 500 volts not alternating. These defects in plugs are thought to be due to metallic dust, although it is difficult, and in fact sometimes impossible, to find the particle causing the trouble. In examining plugs a profile gauge, on which is marked a series of lines normal to the profile, which determine the dimension of the several sections of the plug, is used, and, in addition, the plugs are inserted in a multiple jack in batches of twenty and caused to rotate by rubbing the plug covers with a simple device which consists of a hardwood stick with a mop at the

Gauge of Socket with which Plug is used.	Plug Type No.	Diameter of Hole Mils.	
		Go.	Not Go.
A	201 and 301	249·5	247
B	310	251·5	249
C	309	208	205·5
D	N.T. 2 and N.T. 4	251·25	248·75
E and F	N.T. 5, N.T. 7, N.T. 10	227·25	224·75

end. The mop is rubber covered, and possesses sufficient holding power on the plug cover to cause the plugs to rotate in the jacks. While the plugs are being rotated an alternating E.M.F. of 500 volts is applied to the various sections of the plugs, and a magneto bell and a resistance lamp indicate when the insulation is defective. Fig. 75 is a diagram of the plug-testing board. The two keys Y and Z are used for testing plugs which are fitted with dead rings; Y being for plugs fitted with dead rings between the tip and ring, and Z for plugs fitted with dead rings between the ring and sleeve. The key X is for the ordinary test between the sections of the plug. All dimensions of plugs must be rigidly accurate, including the diameter of the plug covers, or they may be too thick for multiple jacks, and the thread of the screw into which the cord is screwed should be well rounded, so that the cord will not be damaged in the process of screwing in. Cords fitted to switchboard plugs are generally of the tinsel type, the conductor consisting of a minimum of twenty-four ends of tinsel thread laid up in three strands of eight or other equal number of threads each. The lay of the threads is $\frac{1}{4}$ inch and of the strands $\frac{3}{8}$ inch (maximum, $\frac{7}{16}$). The copper plate used in the tinsel thread should be 10 mils by 1 mil (maximum allowable, 13 mils by 1·3 mils) thick, smooth on the

surface and edge, evenly and closely spiralled on a silk thread 5 to 7 mils thick, with not less than 50 or more than 60 turns per inch. The finished conductor should be approximately 50 mils in diameter, and the resistance should not exceed 0·24 ohms per yard at 60° F. The tensile strength of the finished conductor should be not less than 35 lbs., and the finished conductor should withstand the following bending test, which is applied at not less than three different parts of any cord.

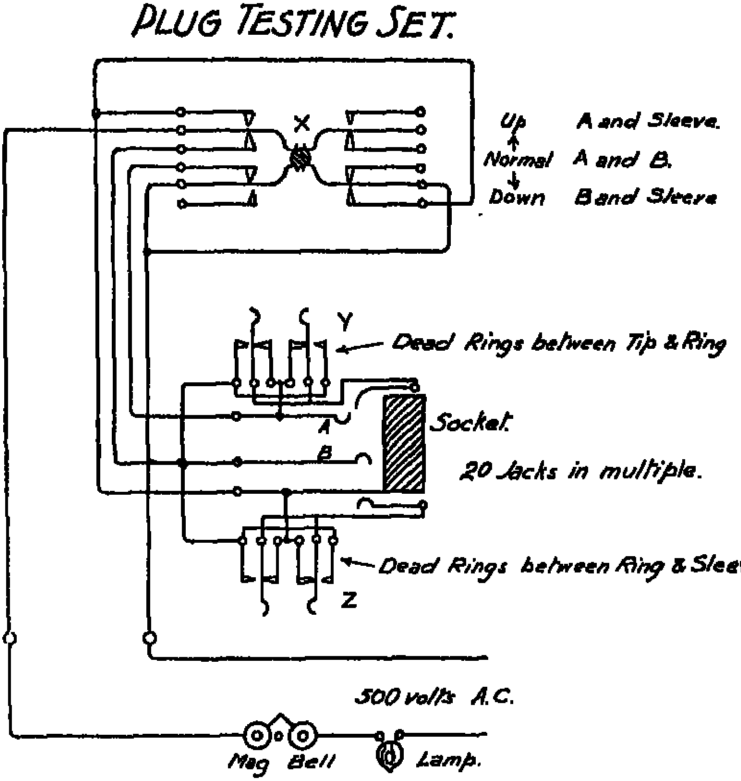


FIG. 75.

Bending Test.—The conductor is gripped in two die-holders, which are ¾ inch apart, the die-holders are caused to approach until they are only ¼ inch apart, and then to recede to their original positions by means of a reciprocating gear driven at 250 revolutions per minute, the die-holders moving in a straight line. The conductor should stand without fracture of the metal of any thread 2000 revolutions under these conditions. The finished conductor should be limp and neutral, that is to say, it should be free from any tendency to drag, kink, spring, or untwist. The coverings of the

conductors should consist of (*a*) two close lappings, lay not more than ⅛ inch, one over the other, of Tussah silk, of a radial thickness of not less than 5 mils; (*b*) a braiding of soft cotton of not less than thirty-two ends of 30/2 cotton from not less than sixteen spindles, each spindle carrying an equal number of ends. The lay of the braiding should not exceed ⅝ inch. For single conductor cords the braiding should be white, two conductor cords, white and blue, and in three conductor cords, white, blue, and red respectively. This type of conductor is also used on instrument cords. It is important with cords to ensure that the mere movement of the cord will not cause noises to be heard in the receiver, and this can generally be determined by bending the cord while holding it close to the ear and listening for any creaking sounds which may be developed. The bindings at the ends of the cords should be neat and free from loose ends and of the correct diameter, especially when the cords are required for use with plugs. The loops and tag-ends should be securely bound, and capable of withstanding a pull of 10 lbs. weight. Waterproof cords which have a layer of stretched pure india-rubber, not less than 6 mils thick after stretching, are identified by the bindings at the ends being of brown silk thread. When tested with a megger, ordinary cords should give not less than 1 megohm for a yard length. At the fastener ends of switchboard cords, and on some instrument cords, a strain cord is provided by a continuation of the outer braiding, so that any strain put on the cord will be taken by this braiding and prevent any damage to, or disconnection of, the conductors.

Switchboard Keys are examined, as a rule, only visually, to ascertain that the pip and plate contacts are well riveted in, and make a good rubbing contact of sufficient spring pressure, that the ebonite parts are properly fitted and unbroken, that the key lever operates satisfactorily, that the handle is at right angles to the mounting plate when in the normal position, that the correct number of springs and contacts is fitted, and the mounting plates are of the correct dimensions and properly marked with type number, engraving, etc. Retardation coils of the ordinary types are tested for resistance and insulation only, unless an impedance is specified when they are tested, as set forth in Chapter .

Switchboard Lamps.—Carbon filaments are almost exclusively used in these lamps, as metal filaments have not so far proved satisfactory. The filament should be of uniform thickness, well shaped, and symmetrically disposed about the axis of the bulb. The leading-out wires should be brought out well clear of each other at the rear of the bulb and securely soldered to the connection plates. The plates should be of tinned brass or tinned copper, firmly cemented to the glass bulb, and the cement should be capable of withstanding a temperature of 212° F. for twenty minutes without the connection plates becoming loose. The following table gives the specified limits for current, candle-power, and watts per candle :—

Title of Lamp.	Current at Normal Voltage.			Watts per C.P. at Normal Voltage.			* Candle-power at Normal Voltage.		
	Minimum.	Standard.	Maximum.	Minimum.	Standard.	Maximum.	Minimum.	Standard.	Maximum.
a.	*b.*	*c.*	*d.*	*e.*	*f.*	*g.*	*h.*	*i.*	*j.*
Volts.									
Lamps No. 2–4 .	·230	·250	·270	6·0	7·5	9·0	·09	·13	·16
" 2–12 .	·097	·107	·117	6·0	7·5	9·0	·14	·17	22
" 2–24 .	·097	·107	·117	6·0	7·5	9·0	·28	·34	·44
" 2–36 .	·065	·075	·084	6·0	7·5	9·0	·28	·36	·46
" 2–40 .	·060	·068	·075	6·0	7·5	9·0	·29	·36	·46
" 2–50 .	·090	·100	·110	8·0	10·0	12·0	·37	·50	·62
" 2*a*–24 .	·046	·050	·054	4·0	5·0	6·0	·20	·24	·30
" 5–10 † .	·180	·190	·200	6·0	7·5	9·0	·21	·25	·32
" 5–36 .	·065	·075	·084	6·0	7·5	9·0	·28	·36	·46
" 3–4 .	·230	·250	·270	6·0	7·5	9·0	·09	·13	·16
" 3–12 .	·097	·107	·117	6·0	7·5	9·0	·14	·17	·22
" 3–24 .	·097	·107	·117	6·0	7·5	9·0	·28	·34	·44
" 4–4 .	·500	·550	·600	8·0	10·0	12·0	·18	·22	·28
" 4–17 .	·106	·114	·123	6·0	7·0	8·0	·23	·28	·34
" 4–24 .	·125	·140	·155	8·0	10·0	12·0	·26	·34	·44

* Candle-power measured in a direction at right angles to the axis of the bulb and to the broadside of the filament. In terms of Vernon Harcourt 1 candle-power standard.
† "Lamps No. 5–10 volts" are used in series.

Lamps Nos. 2, 2A, and 5 should be fitted with wedge-shaped end pieces of hardwood, porcelain or other heat-resisting material, and any space between the rear of the bulb and the end piece should be filled with a hard heat-resisting cement. The end pieces should be in alignment with the bulb, with smooth surfaces, and indelibly coloured to distinguish the voltage of the lamps as follows :—

Voltage of Lamp.	Colour of End Piece.
3	Pink.
4	Green.
10	Brown.
12	Red.
24	Yellow.
36	Black.
40	Blue.
50	White.

The connection plates on all types of lamps should be dimensioned and fitted so that they cannot be short-circuited by means of a flat piece of metal. The ratio of candle-power measured in a direction at right angles to the axis of the bulb and broadside of the filament to that measured in front of the lamp—that is, end on—should be in accordance with the following table :—

Lamp No. and Voltage.	Ratio.		
	Minimum.	Standard.	Maximum.
Nos. 2 and 3 (4 volt)	1·0	1·2	1·4
" (12 volt)	2·0	2·3	2·6
" (24 volt)	2·5	3·0	3·4
No. 2 (36 and 40 volt)	2·5	3·0	3·4
" 2 (50 volt)	3·4	4·0	4·6
" 2A (24 volt)	1·7	2·0	2·3
" 4 (4 volt)	1·0	1·2	1·4
" 4 (17 volt)	2·4	2·6	3·0
" 4 (24 volt)	1·7	2·0	2·3
" 5 (10 volt)	1·7	2·0	2·3
" 5 (36 volt)	2·6	3·0	3·4

The lamps are usually delivered in cardboard cells enclosed in a cardboard box, each box containing either 50 or 100 lamps. Each lamp should have engraved or punched on the connection plate the type number and voltage, and any other marks required by the purchaser.

The lamps are conveniently gauged for dimensions by passing them through a tube of the correct internal diameter. They should be examined to detect any mechanical defects, such as loose connection plates, badly formed or unsymmetrically placed filaments, and badly-shaped or rough end pieces. Each lamp should be tested for continuity of circuit and absence of bright spots in the filament when glowing, due to unevenness in thickness of or damage to the filament. The current, taken at normal voltage, and the candle-power should be measured of a fair proportion of the lamps delivered. For the photometric test a standard ¼ candle-power carbon lamp, properly aged, is a convenient means of comparing the candle-power of the lamps, and a simple form of photometer suffices for the test, providing it is mounted in a dark and non-reflecting case or room. The Post Office Specification stipulates that lamps selected from a delivery shall be capable of withstanding the following number of applications of the normal voltage for fifteen seconds, followed by an interval of five seconds, without the candle-power decreasing more than 20 per cent.

Lamps Nos. 2, 2A, 3, and 5 (4, 10, 12, 24, 36, and 40 volts), 50,000 times.

Lamps No. 2 (50 volts) and No. 4 (4 and 24 volts), 75,000 times.

For this test a clock giving an electrical impulse every second is necessary, and a device for closing and opening the lamp circuit at the appropriate impulses. The latter device consists of an electromagnet, the armature of which operates a pawl engaging with a ratchet wheel. The ratchet wheel is designed so that it makes the circuit for fifteen seconds and breaks it for five seconds. It is important in this test to ensure that the correct voltage is applied to the lamp terminals, as a 10 per cent. increase of voltage

materially decreases the life of the lamps, and *vice versa.* Where lamps of different voltage are under test at the same time, the electrical impulse actuates a number of relaying sounders in parallel, the lamp and appropriate battery being placed in the local circuits of the sounders.

Induction Coils.—The tests applied include the resistance of the windings, insulation resistance coil against coil, which should not be less than 1 megohm and speech efficiency. The last-named test is made by comparison with a standard coil of the same type, the coils being tested in a C.B. or C.B.S. standard circuit depending upon the type under test. The bobbins should be made of well-seasoned mahogany, walnut, or teak, or a paper tube of suitable quality, with ends of mahogany, walnut, or teak. The grain of the wood of the cheeks should be parallel with the holes for the fixing screws, so that there will be no tendency to intermittent disconnections, due to shrinkage of the wood. When the coils are fitted to instruments and switchboards a copper-plated steel spring washer should be inserted under the head of each fixing screw. This washer is

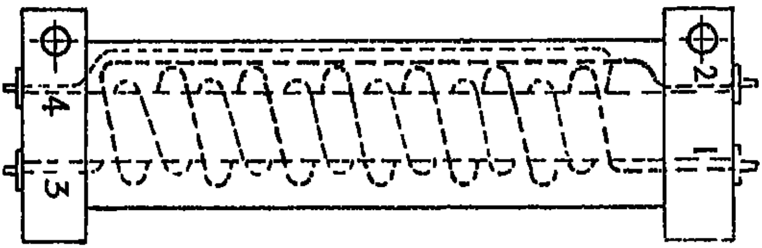


FIG. 76.—Diagram of Windings of Induction Coil No. 3.

usually $\frac{3}{8}$ inch diameter, $\frac{3}{64}$ inch thick centre hole clear for No. 5 B.A. screw, split from centre to edge, and opened to $\frac{3}{32}$ inch over all. The core should be made up of No. 24 S.W.G., well annealed charcoal iron wire, left black from the annealing process, or of Hadfield's special steel alloy, known as "B" alloy, No. 24 S.W.G. The ends of the wires should be flush with the coil cheeks, and the core should completely fill the hole in the bobbin. The coils should be covered with bookbinder's cloth. The resistances of the primary and secondary windings should be neatly stamped on the coil cheeks. The dimensions and markings should agree with the pattern. The table on following page gives the details of the coils principally used.

The direction of the windings should be checked. The following method is convenient for checking the coils of types 3 and 4. Place a small pocket compass on the coil; connect one lead from a 2-volt battery to terminals numbered 1 and 4; tap the other lead from the battery on terminals 2 and 3 in turn; the needle should deflect in the same direction in each case. Fig. 76 shows the windings of coils No. 3.

Bridging Coils.—The core should be of annealed Swedish charcoal iron, and the sheath and mounting plate of soft iron of good quality, well annealed. Fixing screws for core and sheath should be iron. The sheath, mounting plate, and fixing screws should be white nickelled. Each end of the core should be coarse milled, and the ebonite coil cheeks forced on over the milling to the correct positions. On one end of the core a tongue should be formed to engage either

Type No.	Resistance Ohms.		Number of Turns or Gauge of Wire.		Remarks.
	Primary.	Secondary.	Primary.	Secondary.	
1	1	25	25 mils	11 mils	——
2	1	150	"	7 mils tinned copper	——
3	26	17	1400	1700	The inner coil is the 26-ohm coil of 1400 turns.
4	26	17	1400	1700	
6	11	240 + 58	—	—	The two sections of the secondary should be wound in the same direction.
8	18 + 18	130 + 130 with 360 non-inductive	—	—	Two induction coils in series on same base. Operator circuit, No. 1 C.B. Exchange.
9	26	17	1400	1700	——
10	1·7	75	—	—	Used with Lineman's portable set. Telephone No. 44.
11	Similar to No. 8.				
N.T. 6	3	Ten sections, each 150 ohms	—	—	Busyback.
N.T. 10	Four sections 1·3, 1·6, 1·9, 2·2	17	Four sections, each 320 turns	2000 turns	Electrophone.
N.T. 11	1	12·5 + 12·5	—	—	The two sections of secondary should act in the same direction.
12	1	25	—	—	——
13	1	25 + 10	—	—	——

with the sheath or mounting plate for fixing the sheath, and both ends of the core should be tapped for a No. 3 B.A. screw. The brass tags should be tightly screwed into the coil cheek, central with the holes of the sheath, and the ends coated with solder to facilitate wiring. The inside of the sheath should be smooth and free from rust. The sheath should be an easy fit over the coil cheeks. The brass terminals and fixing screws for mounted coils should be tinned. The ebonite mounting should not be polished.

The coils should be wound with single silk-covered, tinned copper wire of the diameter shown in the following table :—

Type Nos.	Type Letter.	Diameter of Wire Mils.	Resistance Ohms.
1 and 6	A	6	100
"	B	6	120
"	C	5	200
"	D	5	250
"	E	5	300
"	F	4	500
"	G	4	600
"	H	$3\frac{1}{2}$	750
"	J	$3\frac{1}{4}$	1000
"	K	9	50
"	L	3	1400
"	N	—	5000
4, 5, and 7	A	4	200 + 200
"	B	3	600 + 600
"	C	3	500 + 500

The coil ends should be led out by means of double silk-covered tinned copper wire, 14 mils diameter. The resistance should be within 5 per cent. either way, and for double coils the difference in resistance between the two coils should not exceed 1 per cent. The insulation resistance between the coils and between coil and frame should be not less than 1 megohm.

Meters.—Very stringent tests are applied to all meters to ensure that they are absolutely accurate throughout the whole of the range of their counting mechanism. The meters must register correctly 10,000 times without readjustment, with the operating current applied for half a second every second. The make and break are conveniently obtained by means of a disc, one half of which

Type.	Resistance, Ohms.	Operating Current, Milliamperes.	Releasing Current, Milliamperes.	Non-operating Current, Milliamperes.	Remarks.
1A	500 + 40	40	15 after 60 have been applied for 1 second.	37*	* This test should be made with the units wheel not in gear with the tens wheel.
2B	0·27	1300	Disconnection after 2200 (2·2 amperes).	1200	—
2A	500	40	Disconnection after 78.	37	—
3A	500 + 50	60	17 after 96 have been applied for 1 second.	30	—
4A	500	72	Disconnection after 104.	30	—
4B	0·4	1100	Disconnection after 2170 (2·17 amperes).	900	—

is metal and the other half fibre, attached to a shaft driven at 60 r.p.m. through worm gearing by a motor. All those that either gain or lose more than 1 in 10,000 are put aside to be overhauled and readjusted. Large batches are tested simultaneously, a standard counting mechanism being attached to the interrupter shaft to check the number of impulses. The insulation resistance between the coil and the frame should be not less than 100 megohms when tested with a 250-volt megger. The relay testing set described on page 198 is convenient for applying the various operating, etc., currents, details of which are shown in the above table.

CHAPTER XIV

SWITCHBOARDS

Although each operation in the testing of a switchboard is of a simple and straightforward character, the complete test is somewhat complicated, and to ensure that all those parts are checked and tested that ought to be tested entails the following out of a definite scheme. Each expert testing officer has his own views on the scheme to be followed, but those set forth below represent the essential details in something like logical order for each type of board, and will give a sufficient indication of the methods usually followed. The Combination testing set is admirably adapted for roughly checking the resistance between two points on the board, as the needle swings quickly and almost dead beat to the ohms reading immediately connection is made with the testing leads, which terminate in an improved form of tie-clip. The tie-clips afford an excellent means of making reliable and rapid connection with the tags and sections of the plugs. In testing between the tip and ring of the plug it is sometimes convenient to connect the tie-clips of the testing leads to the A and B tags of a jack, and to test the connections to the plugs by plugging into this jack. The checking of the mechanical details of keys, jacks, plugs, cords, indicators, relays, induction coils, and bells is best done before the apparatus is assembled and fitted on the board. The condensers, relays, and indicators are tested electrically before fitting. The mechanical examination of the switchboard is therefore confined to checking dimensions, quality, and finish of the materials of construction, and especially the wiring and joints. There should be no "dry" joints, that is to say, the wires should be reliably soldered to the tags, etc., and should not contain any loose connections. Occasionally the solder does not take properly, and when this is the case the wire can be moved with the finger. The coverings of the wire should be left close up to the soldered connection, the ends being bared only just far enough to enable the joint to be made. Sufficient slack should be left in wiring to allow of any piece of apparatus being taken out and replaced. The wiring should be cabled and neatly run, and finished with a good glossy surface by coating with good shellac. The wire generally used is 9½ lbs. copper, silk and cotton covered, treated with best beeswax. The cabling should be cleated down so that no part of it will be damaged when the doors or lids are closed. The cord weights should not foul the

cabling. The line tags should be marked with the numbers of extension and Exchange lines. The bus bars for the power leads should be marked + and −, and the fuse posts should be numbered. The sockets of the jacks should be of the specified diameter, steel rod gauges being generally used to check this dimension. All apparatus on the board should be marked with its appropriate type-marking. In testing the board electrically it is advisable to begin by checking the operation of the indicators and relays with the specified figure-of-merit currents (the currents being applied direct to the tags of the apparatus), as it is occasionally found that the adjustment of the apparatus has been altered during the fitting process or in transit from the workshop to the test-room. The next step is the checking of the resistances between the points shown in the following schedules, then the insulation resistance of the wiring, etc., and finally the operating tests. It is unnecessary to include more than one type of each board in the following tests, as the details are the same in all sizes of boards of the same type. As a rule switchboards are purchased only partly equipped. For example, Switchboards Branch Exchange Common Battery $\frac{5+20}{25}$ are also supplied equipped for three instead of five Exchange lines, and ten instead of twenty extension lines, and are described as $\frac{3+10}{25}$, the denominator indicating the full capacity of the switchboard. A varnished diagram of the electrical connections of the switchboard is fixed to the inner side of the back of the switchboard. Fig. 77 shows the wiring of the board and Fig. 78 a simplified diagram arranged to facilitate testing operations.

SWITCHBOARDS B.E.C.B. $\frac{3+10}{25}$ AND $\frac{5+20}{25}$ (LINE INDICATOR CLEARING), MARK 235.

	Figure of Merit Currents. Milliamperes.
Indicator No. 405 E.N.	9
Exchange indicator No. 105 A.R. . .	6 (coils in series).
Relay No. 119 A.O.	32·5*
Relay and Coils No. 7 A.O. . . .	10·9

(For Table see p. 235.)

Insulation of the lines on the board is tested with 100-volt megger.

Extension Lines.—All fuse terminals connected to negative bus bar and local bell switched on. Test between positive and negative of bus bars.

Exchange Lines.—Test between A and B wires of all lines and test A and B wires of Exchange lines against frame. The insulation resistance between any two points should be not less than half a megohm.

* Mean of operating currents.

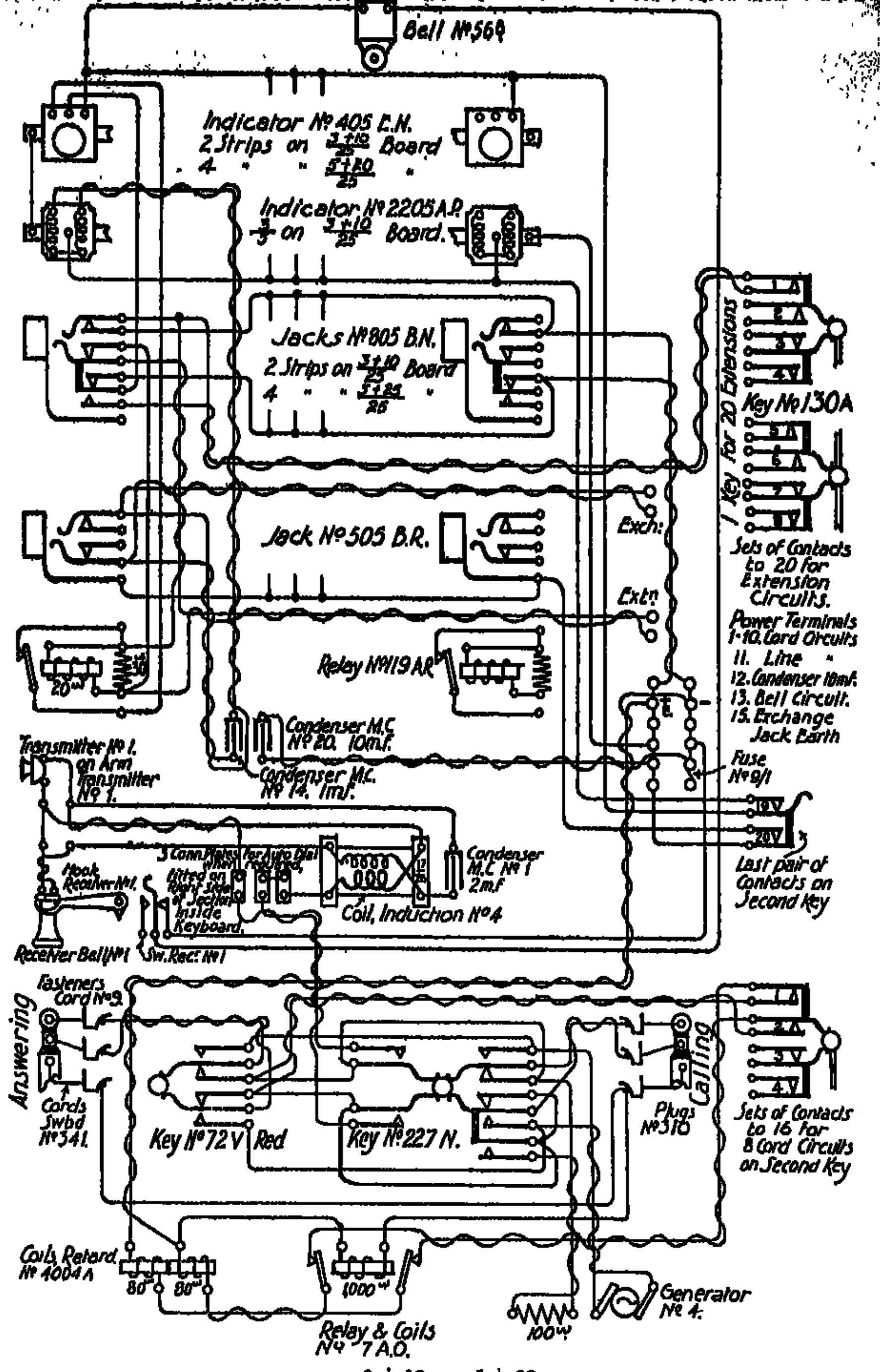


FIG. 77.—Switchboard B.E.C.B. $\frac{3 + 10}{25}$ and $\frac{5 + 20}{25}$. Mark 235. Line Indicator Clearing. Wiring Diagram.

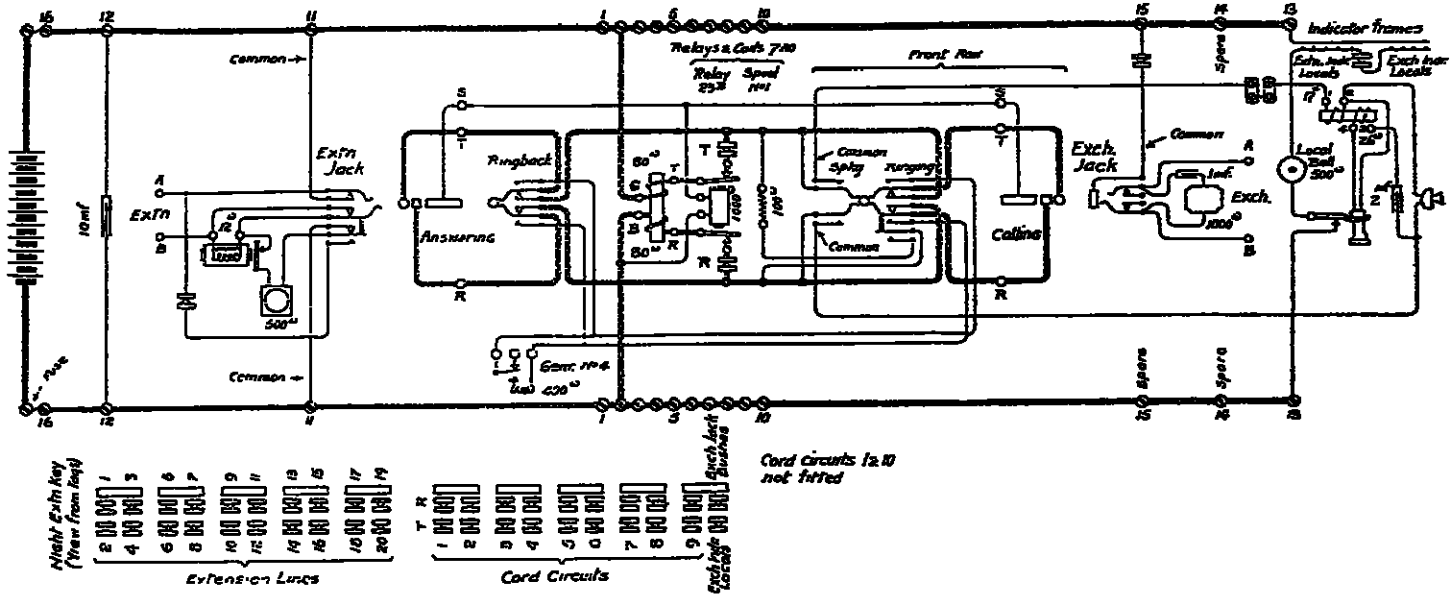


FIG. 78.—Testing Diagram of Switchboard B.E.C.B. $\frac{3+10}{25}$ and $\frac{5+20}{25}$. Mark 235.

RESISTANCE TESTS.

Circuit.	Testing Leads Connected to.	Other Connections to be Made or Checked.	Resistance Ohms.	Apparatus in Circuit.
Exchange lines.	A. and B.	Short circuit condenser.	1000	Exchange indicators.
Extension lines.	B and No. 11 fuse terminal.	Disconnect by putting plug in jack, and by operating indicator cut-off relay.	500	Extension indicators.
Do.	A and B.	Plug in extension jack. Disconnect by operating night switch.	512	Extension indicators and relays.
Night bell.	Positive and No. 13 fuse terminal.	Drop any extension or exchange indicator and depress switch hook. Disconnect by raising switch hook. Disconnect by operating night switch.	500	Bell 13B.
Cord.	Positive and tips of one row of plugs.	Disconnect by operating night switch and cut off relay.	80	"A" winding of retardation coil.
Do.	Fuse terminals and rings of one row of plugs.	Do.	80	"B" do.
Do.	Fuse terminals and sleeves of one row of plugs.	——	1000	Battery cut off relay.
Do.	Tip and ring of answering plugs.	Ringing key operated.	100	Resistance spool.
Do.	Tip of one plug and one side of receiver.	Speaking key operated.	17	Primary of induction coil.
Do.	Tip of one plug and other side of receiver.	Do.	77	Primary of induction coil and receiver.
Do.	Tip of one plug and one side of operator's condenser.	Do.	103	Primary of induction coil; receiver and secondary of induction coil.
Do.	Tip and ring of one calling plug.	Ringing key operated.	400	Generator.

Test direction of windings of induction coil as set forth on page 227.

Exchange Calling Indicators.—Test all indicators by ringing on Exchange line tags. Ring local bell in each case and operate night switch, which should cut off local bell.

Operating Test.—Connect No. 1 Exchange line to a model Exchange, also connect a 20-volt battery with detector in series to the bus bars. Insert a plug in No. 1 Exchange jack, which should cut off local battery. Speak to Exchange through 30 miles of artificial standard cable. In the case of answering plugs, operate the ringing key and ascertain that Exchange is still held. Repeat until all plugs and Exchange jacks have been tested. Connect a

telephone No. 1 to extension tags No. 1 and ring out on all cords. Raise the switch hook of this telephone. The calling indicator should operate. Ring local bell by depressing operator's switch hook. Take the first pair of cords, insert answering plug in extension jack No. 1, and ascertain that indicator restores. Speak to and ring extension. The indicator should operate when extension clears. Operate the night switch, which should prevent the clearing signal from being given. Transfer the telephone No. 1 to extension line No. 2, and repeat the test, using the calling plug of the same pair. Continue until all calling and answering plugs and all extension lines have been tested.

Overhearing.—Plug each cord circuit through to a buzzer circuit and listen on the remaining cord circuits. No overhearing should be perceptible. The buzzer should be placed far enough away from the board to prevent its being heard direct.

It will be noticed that the extension clears to this board by hanging up the receiver, which disconnects the relay in the B line and energises the indicator, giving a positive clear. Formerly boards of this size were supplied on which the indicators were energised during the conversation and de-energised on clearing, thus giving a negative clear to the Branch Exchange board, an arrangement which proved unsatisfactory in practice. Negative clearing is still in use, however, on larger boards, and as an example of this type, switchboards B.E.C.B. $\frac{10 + 50}{65}$ or $\frac{10 + 30}{65}$ may be taken. The procedure followed is similar to the foregoing. Fig. 79 shows the wiring of the board, and Fig. 80 is a simplified diagram arranged to facilitate testing operations.

Insulation (100 volt megger) *Extension Lines.*—All fuse terminals should be connected to negative bus bar. Connect up operator's set, switch on local bell, throw one speaking key and transmitter cut-out key. Leave all indicators normal and plugs out of jacks. Test between positive and negative bus bars. Disconnect transmitter, restore transmitter cut-out key, and repeat test. Insulation resistance not less than half a megohm.

Exchange Lines.—Test between all A and B tags. Test A and B Exchange line tags against earth (all keys normal).

Exchange Calling Indicators.—Drop all calling indicators by ringing on Exchange line tags. Ring local bell in each case.

Bridging Coil Cut-off Relays.—Connect 20-volt battery in series with a milliammeter to No. 1 Exchange line tags, plug in, and note deflection. Operate night extension key, milliammeter reading should fall to zero. Restore key to normal. Insert the other plug of the pair into the cord circuit test jack. The deflection should decrease and the clearing indicator should operate. Repeat for all Exchange lines.

Battery Cut-off Relays and Clearing Indicators.—Connect a 20-volt battery to the bus bars. Insert calling plug of first cord into cord testing jack. Clearing indicator should operate. Insert

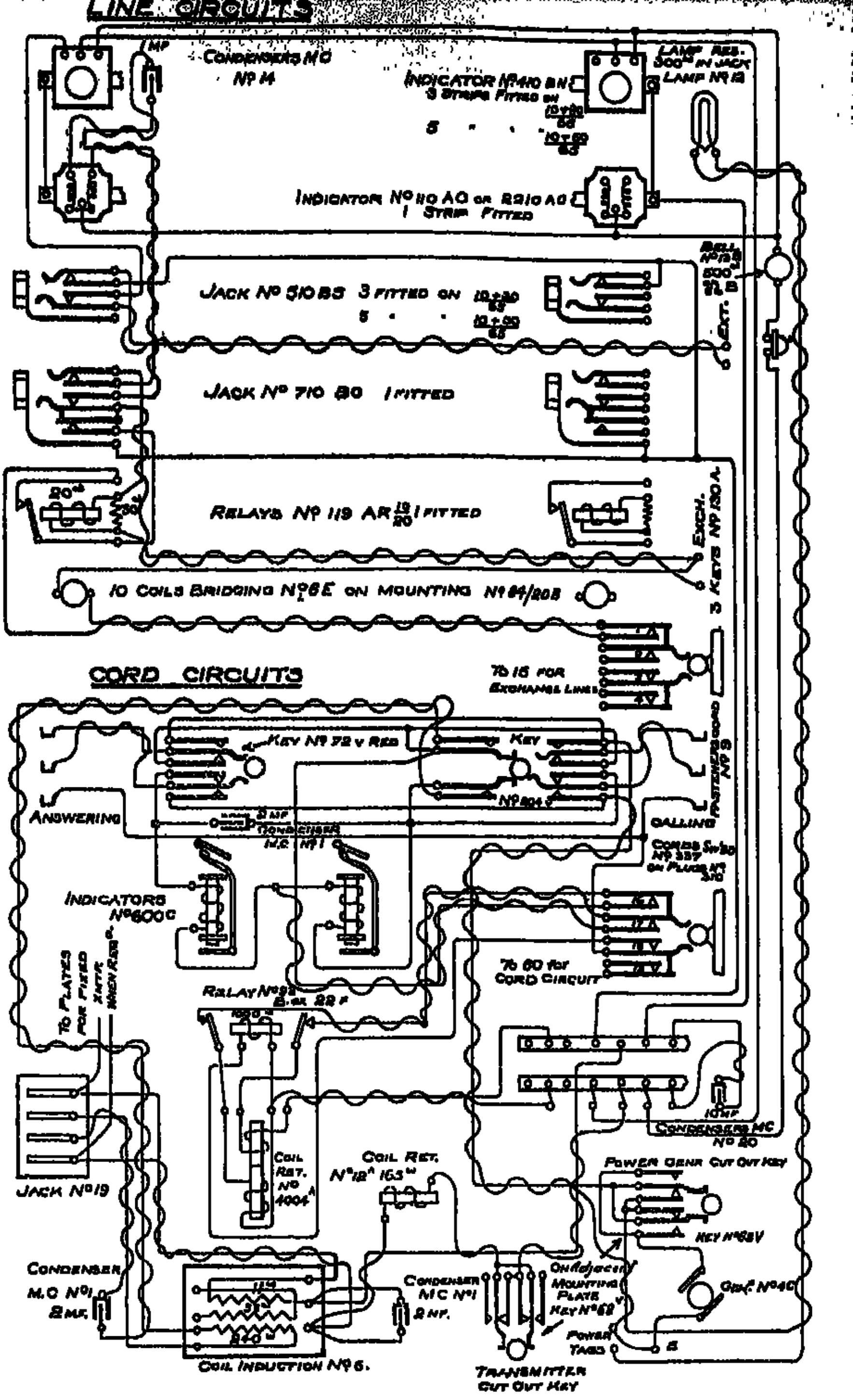


Fig. 79.—Switchboard B.E.C.B. $\frac{10 + 30}{65}$ and $\frac{10 + 65}{65}$. Wiring Diagram.

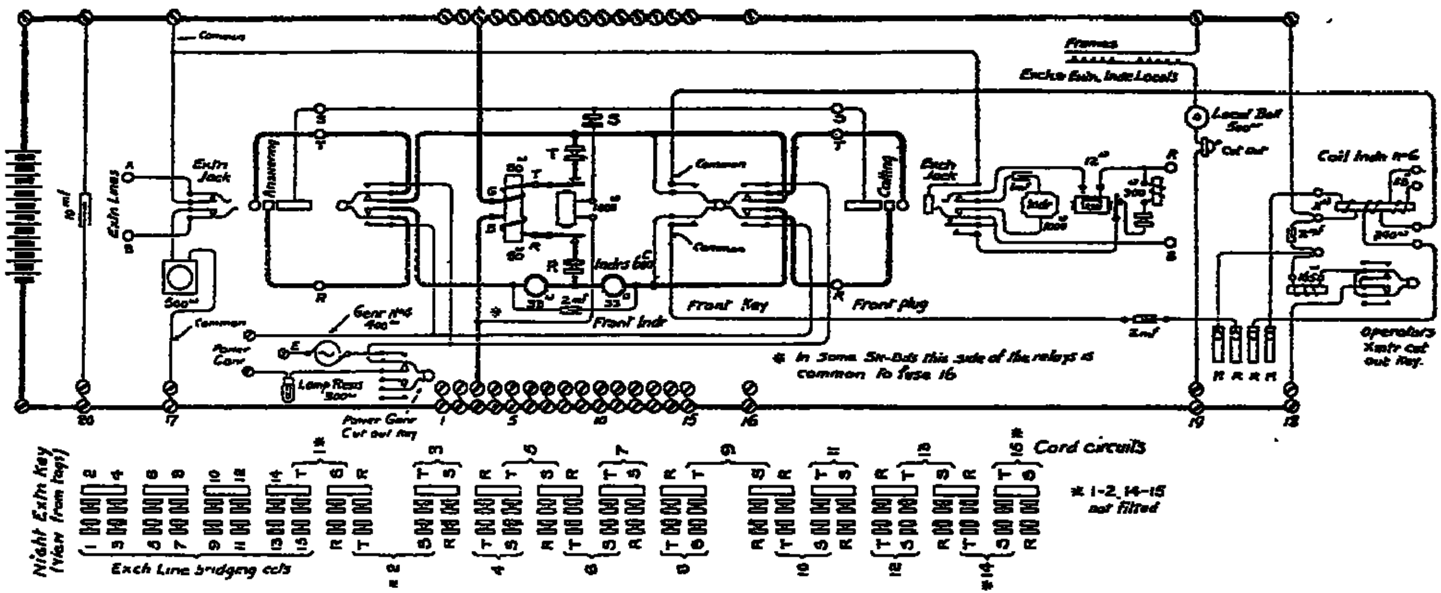


FIG. 80.—Switchboard B.E.C.B. $\frac{10+30}{65}$ and $\frac{10+50}{65}$. Testing Diagram.

	Figure of Merit Currents, Milliamperes.
Indicator No. 600C. (cord circuit) .	25
Extension indicators No. 410 B.N.	9
Exchange indicators No. 110 A.O.	6 (coils in series)
Relays No. 119 A.O.	32·5*
Relays No. 23 B.N.	10·9

RESISTANCE TESTS.

Circuit.	Testing Leads Connected to.	Other Connections to be Made or Checked.	Resistance Ohms.	Apparatus in Circuit.
Exchange lines.	B side of Exchange condenser and B line tags.	*Nil.*	1000	Exchange indicators.
Do.	A side of Exchange condenser and A line tags.	*Nil.*	12	Bridging coil cut-off relay.
Do.	A and B tags.	Plug in Exchange jack. Disconnect by operating night switch and by operating bridging coil cut-off relay.	300	Bridging coil.
Extension lines.	B tags and fuse terminal 17.	*Nil.*	500	Extension indicator.
Cord testing jack.	A and B springs of jack.	Disconnect by operating night switch.	400	Resistance spool.
Local bell.	Fuse terminal 19 and positive bus bar.	One indicator operated and local bell switched on.	500	Local bell.
Cord.	Fuse terminals 1 to 15 and rings of one row of plugs.	Disconnect by operating night switch.	113	B winding retardation coils (80) and clearing indicator (33).
Do.	Fuse terminal 1 and sleeves of one row of plugs.	Do.	1000	Battery cut-off relays.
Operator's.	Positive bus bar and fuse terminal 18.	Short circuit condenser. Disconnect by operating transmitter cut-out key.	165	Operator's retardation coil.
Do.	Positive bus bar and one transmitter spring.	*Nil.*	11	Primary winding of induction coil.
Do.	Tip of any plug and inner spring of operator's jack.	Throw speaking key.	240	Secondary winding of induction coil.
Cord.	Positive bus bar and tips of one row of plugs.	Disconnect by operating night switch.	80	"A" windings of retardation coils.
Do.	Ring of one row of plugs and ring of other row of plugs.	*Nil.*	66	Clearing indicators.
Do.	Power generator E terminal and tip of calling plug.	Operate ringing key and turn generator handle.	400	Generator.
Do.	Power generator ± terminal and tip of plug.	Operate ringing key.	300 (approx.)	Resistance lamp.

* Mean of operating currents.

answering plug in Exchange jack No. 1. The cut-off relay should operate cutting off the battery from the clearing indicator, which should return to normal. Reverse the plugs and repeat until all cords and all Exchange jacks have been tested.

Extension and Cord Circuits.—Leave 20-volt battery on the bus bars. Connect a telephone No. 1 to extension tags No. 1 and raise the switch hook. Calling indicator should operate. Switch on local bell, which should ring. Take first pair of cords, insert answering plug in extension jack No. 1, and indicator should restore. Speak to extension and ring out with ring back key, using hand and power generators. Insert calling plug in extension jack No. 1, ring out, using hand and power generators, and speak to extension. Operate night switch, which should cut off speech.

Repeat until all calling and answering plugs and all extension line circuits have been used.

Operator's Set. Speech Efficiency.—Connect one of the Exchange circuits to model Exchange and speak through 30 miles of artificial standard cable.

Overhearing.—Plug each cord circuit through to a buzzer circuit, and with a receiver listen on the remaining cord circuits. No overhearing should be perceptible.

CORDLESS SWITCHBOARDS BRANCH EXCHANGE COMMON BATTERY POSITIVE CLEARING (MARK 234), $\frac{1+3}{4}$, $\frac{2+4}{6}$ or $\frac{3+7}{12}$.

Fig. 81 is a wiring diagram and Fig. 82 is a simplified testing diagram.

	Figure of Merit Currents. Milliamperes.
Exchange indicators No. 100A . .	6 (coils in series).
Extension indicators No. 400B . .	9
Relays No. 119A	32·5*

(For Table see p. 243.)

Insulation.—100 volt megger. Test A line against B line of all Exchange lines. With operator's key thrown, test positive bus bar against negative bus bar. Test A line and B line of Exchange lines against frame. Insulation resistance should be not less than 1 megohm.

Exchange Indicators.—Drop all indicators by ringing on Exchange line tags. Switch on buzzer and note that it operates in each case. Operate night switch, which should disconnect the buzzer circuit.

Operating Test.—Connect a 20-volt battery to the bus bars, a telephone No. 2 to the operator's telephone terminals, and a telephone No. 1 to No. 1 extension line tags.

Operate No. 1 extension line indicator by lifting receiver of

* Mean of operating currents.

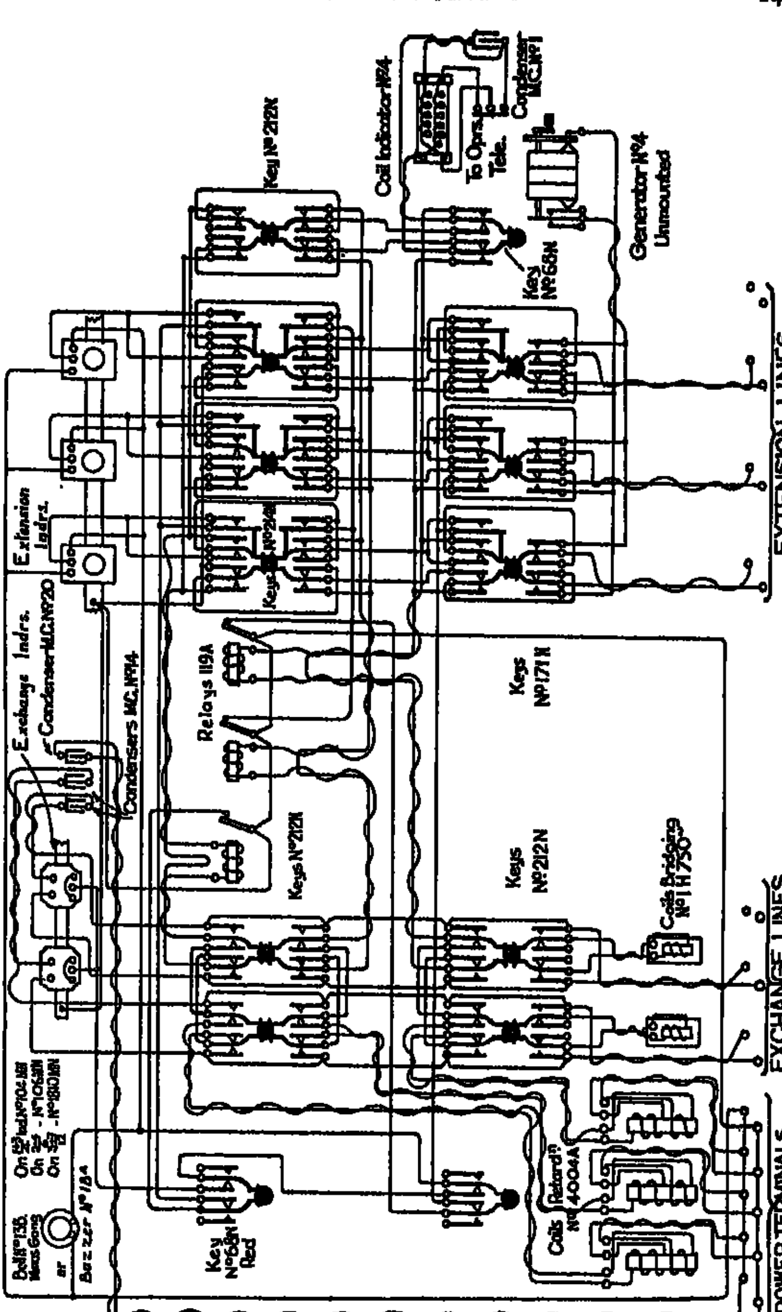


FIG. 81.—Switchboard B.E.C.B. Cordless (Mark 235) Positive Clearing. Wiring Diagram.

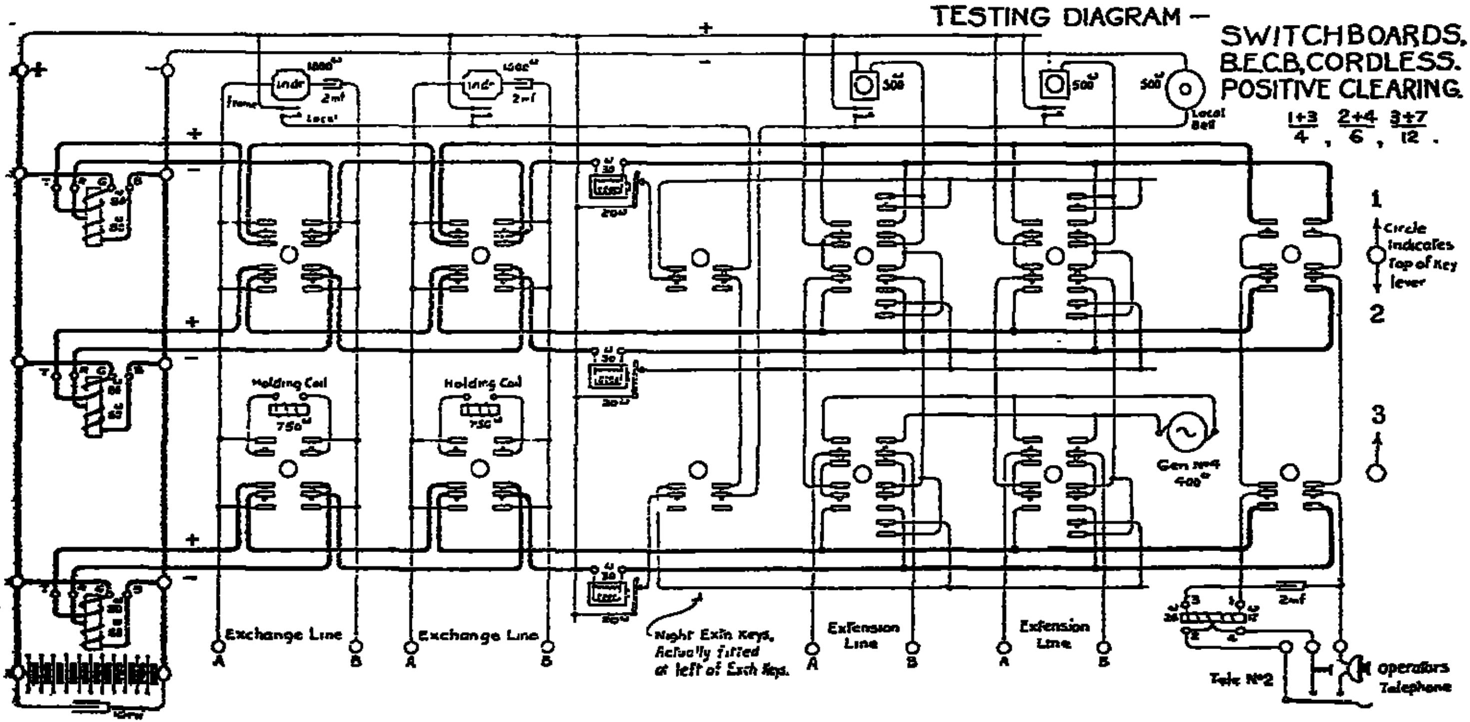

TESTING DIAGRAM — SWITCHBOARDS, B.E.C.B. CORDLESS. POSITIVE CLEARING.
$\frac{1+3}{4}$, $\frac{2+4}{6}$, $\frac{3+7}{12}$.
1
Circle indicates Top of Key lever
2
3
Holding Coil
750
Holding Coil
750
Exchange Line
Exchange Line
Night Exn Keys. Actually fitted at left of Exch Keys.
Extension Line
Extension Line
Gen No 4
400
Local Bell
Tele No 2
operators Telephone
2mf
A
B
A
B
A
B
A
B

Fig. 82.

RESISTANCE TESTS.

Circuit.	Testing Leads Connected to.	Other Connections to be Made or Checked.	Resistance Ohms.	Apparatus in Circuit.
Exchange lines.	A and B line tags.	Short circuit condenser.	1000	Calling indicator.
Do.	Do.	Operate Exchange holding key. Take short circuit off condenser.	750	Holding coil.
Extension lines.	Negative of bus bar and B line tag.	Disconnect by operating ringing key.	500	Extension indicator.
Buzzer.	Positive and negative bus bars.	Operate Exchange indicator.	500	Buzzer.
Connecting.	Negative of bus bar and B line tag of No. 1 extension line.	Operate each connecting circuit key in turn.	92	Relay 119A and B winding of retardation coil.
Do.	Positive of bus bar and A line tag of No. 1 extension.	Do.	80	A winding of retardation coil.
Ringing.	A and B line tags of any extension.	Operate ringing key.	400	Generator.
Operator's.	Terminals on mounting.	Test direction of windings as described on page 227.	17	Primary of induction coil.
Do.	Do.	Do.	26	Secondary of induction coil.

extension telephone. Buzzer should operate. Ring out from the switchboard and speak on each connecting circuit. The line indicator should restore when the connecting circuit is completed and operate again when the extension clears. Operate the relative night switch, which should prevent the clearing signal being given. Repeat for all extension lines.

Connect No. 1 Exchange line tags to a model Exchange. Call exchange by operating (1) relative Exchange key; (2) operator's key; and (3) lifting operator's receiver. Speak to the Exchange through 30 miles of artificial standard cable, using each connecting circuit in turn. Repeat for all Exchange lines.

Overhearing.—Connect a separate buzzer circuit to No. 1 extension line and switch through to No. 1 connecting circuit. Listen on the other connecting circuits in turn. Switch the buzzer circuit to No. 2 connecting circuit and repeat as above until all connecting circuits have been tested. No overhearing should be perceptible.

CORDLESS SWITCHBOARDS B.E.C.B. $\frac{1+3}{4}$, $\frac{2+4}{6}$, $\frac{3+7}{10}$. NEGATIVE CLEARING.

Fig. 83 is a wiring diagram and Fig. 84 a testing diagram.

	Figure of Merit Currents, Milliamperes.
Exchange indicators No. 100A . .	6 (coils in series).
Extension indicators No. 400E . .	9
Clearing indicators No. 500C. . .	24

RESISTANCE TESTS.

Circuit.	Testing Leads Connected to.	Other Connections to be Made or Checked.	Resistance Ohms.	Apparatus in Circuit.
Exchange.	A and B tags.	Short circuit condenser.	1000	Exchange indicator.
Do.	Do.	Operate Exchange holding key. Take short circuit off condenser.	750	Holding coil.
Extension.	Negative of bus bar and B line tag.	Disconnect by operating ringing key.	500	Extension indicator.
Buzzer.	Positive and negative bus bars.	Operate Exchange indicator and local buzzer key.	500	Buzzer.
Connecting.	Negative of bus bar and B tag of No. 1 extension.	Throw key to each connecting circuit in turn.	85	B winding of retardation coil.
Do.	Positive of bus bar and A tag of No. 1 extension.	Do.	135	A winding of retardation coil plus clearing indicator.
Ringing.	A and B tags of any extension line.	Operate ringing key.	400 (No. 4C). 500 (No. 2A).	Generator 4C or 2A, whichever fitted.
Operator's.	Terminals on mounting.	Test direction of winding (see p. 227).	17	Primary of induction coil.
Do.	Do.	Do.	26	Secondary of induction coil.

Insulation (100-volt megger) *Exchange Lines.*—Test A against B of all lines, and A and B tags against frame.

Extension Lines.—Operate local buzzer key and test positive bus bar against negative. Restore local buzzer key and throw operator's speaking key. Test positive against negative bus bar. Minimum insulation, 1 megohm.

Exchange Indicators.—Switch in local buzzer and drop all indicators by ringing on Exchange line tags.

Operating Test.—Connect a 20-volt battery to the bus bars, a telephone No. 2 to the operator's telephone terminals, and a telephone No. 1 to No. 1 extension line tags. Operate No. 1 extension line indicator by lifting receiver of extension telephone. Local buzzer

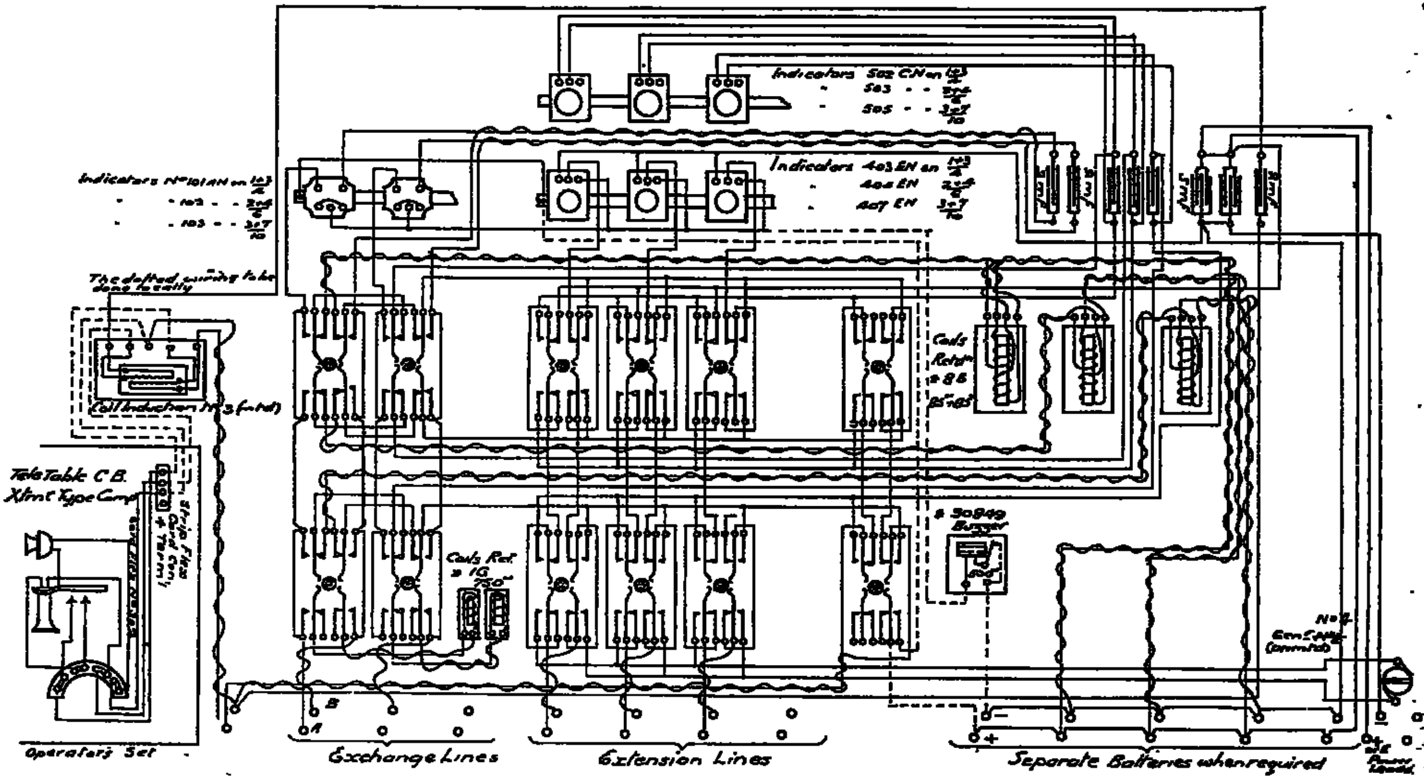


FIG. 83.—Cordless Switchboard B.E.C.B. $\frac{1+3}{4}$, $\frac{2+4}{6}$, $\frac{3+7}{10}$. Wiring Diagram.

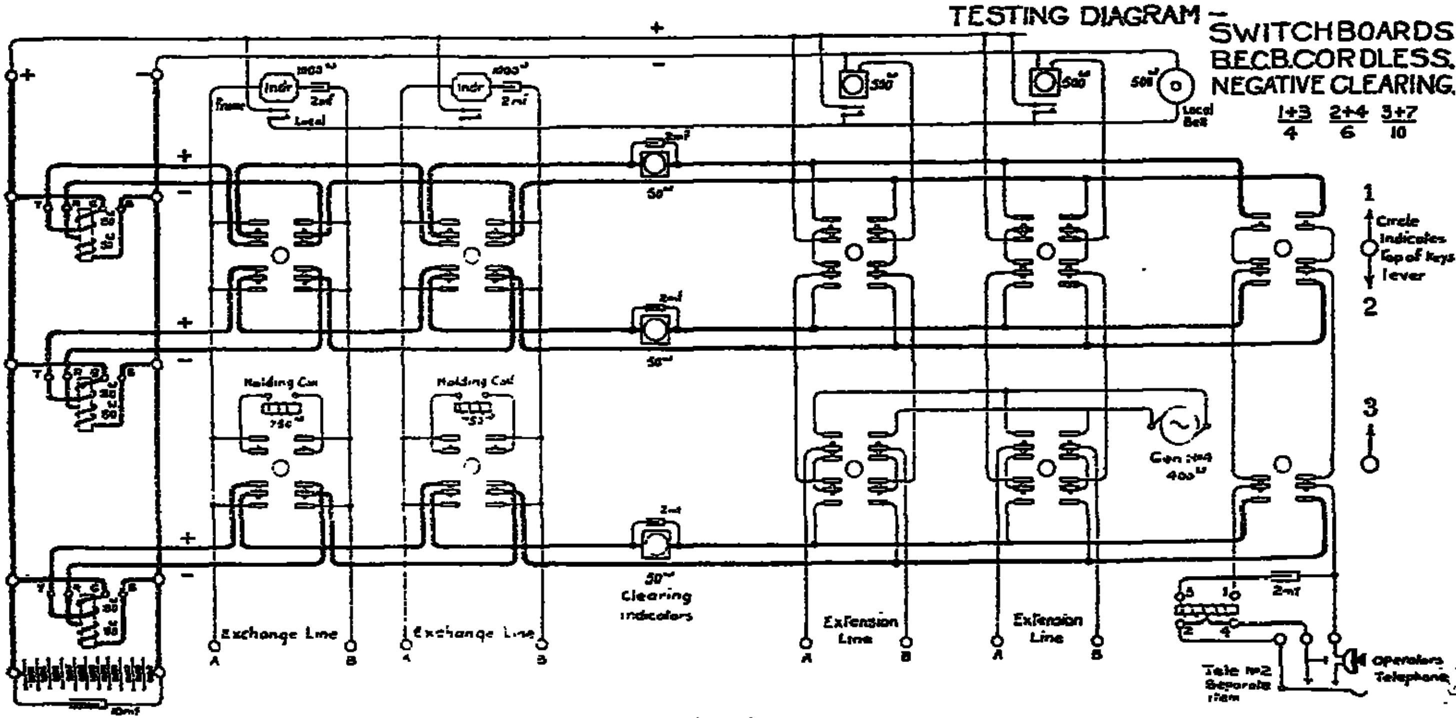

TESTING DIAGRAM — SWITCHBOARDS B.E.C.B. CORDLESS. NEGATIVE CLEARING.
Circle indicates top of keys lever
Exchange Line
Extension Line
Holding Coil
Clearing indicators
Operators Telephone
Local Bell
Frame
Local
A
B

Fig. 84.

should operate. Ring out from the switchboard and speak on each connecting circuit. On switching through to a connecting circuit the line indicator should restore. The clearing indicators should restore when the extension clears and be operated during the time the extension is engaged. Repeat for all extension lines. Connect No. 1 Exchange line tags to a model Exchange. Call Exchange by operating relative Exchange key, also operator's key, and lift operator's receiver. Speak through 30 miles of artificial standard cable, using each connecting circuit in turn. Repeat for all Exchange lines.

Overhearing Test.—Connect a separate buzzer circuit to No. 1 extension line and switch through to No. 1 connecting circuit. Listen on the other connecting circuits in turn. Switch the buzzer circuit to No. 2 connecting circuit and repeat as above until all connecting circuits have been tested. No overhearing should be perceptible.

SWITCHBOARDS MAGNETO C.B.S. (COMMON BATTERY SIGNALLING)
$\frac{1+4}{5}$, $\frac{2+3}{5}$, $\frac{1+9}{10}$, $\frac{2+8}{10}$, $\frac{2+13}{15}$, $\frac{2+18}{20}$, and $\frac{4+26}{30}$.

Fig. 85 is a wiring diagram.

	Figure of Merit Currents. Milliamperes.
Exchange indicators No. 100A . .	6 (coils in series).
Extension indicators No. 100A . .	6 "

RESISTANCE TESTS.

Circuit.	Testing Leads Connected to.	Other Connections to be Made or Checked.	Resistance Ohms.	Apparatus in Circuit.
Exchange.	A line tag and earth.	*Nil.*	1000	Exchange indicator.
Extension.	A and B line tags.	Short circuit condenser.	1000	Extension indicator.
Ringing.	A and B tags of any extension line.	Operate ringing key and generator cut off.	500 (2A) 400 (4C)	Generator 2A or 4C whichever fitted.
Local bell.	Local battery connection plates.	Operate bell switch and an indicator.	25	Bell winding.
Operator's.	Terminals on mounting.	*Nil.*	1	Primary induction coil.
			150	Secondary induction coil.
Do.	Receiver terminals.	Do.	60	Receiver winding.

Insulation (100-volt megger) *Exchange Lines.*—Test B lines only against earth terminal.

Extension Lines.—Test A against B tags and A and B against earth terminal. Plugs tip against ring. Induction coil. Secondary against primary and receiver case.

Exchange Indicators.—Join up 4 micro-farad condensers and

CONNECTIONS OF SWITCHBOARDS MAGNETO (C.B.S) AND CASE WITH CONDENSERS 4 AND 2MF

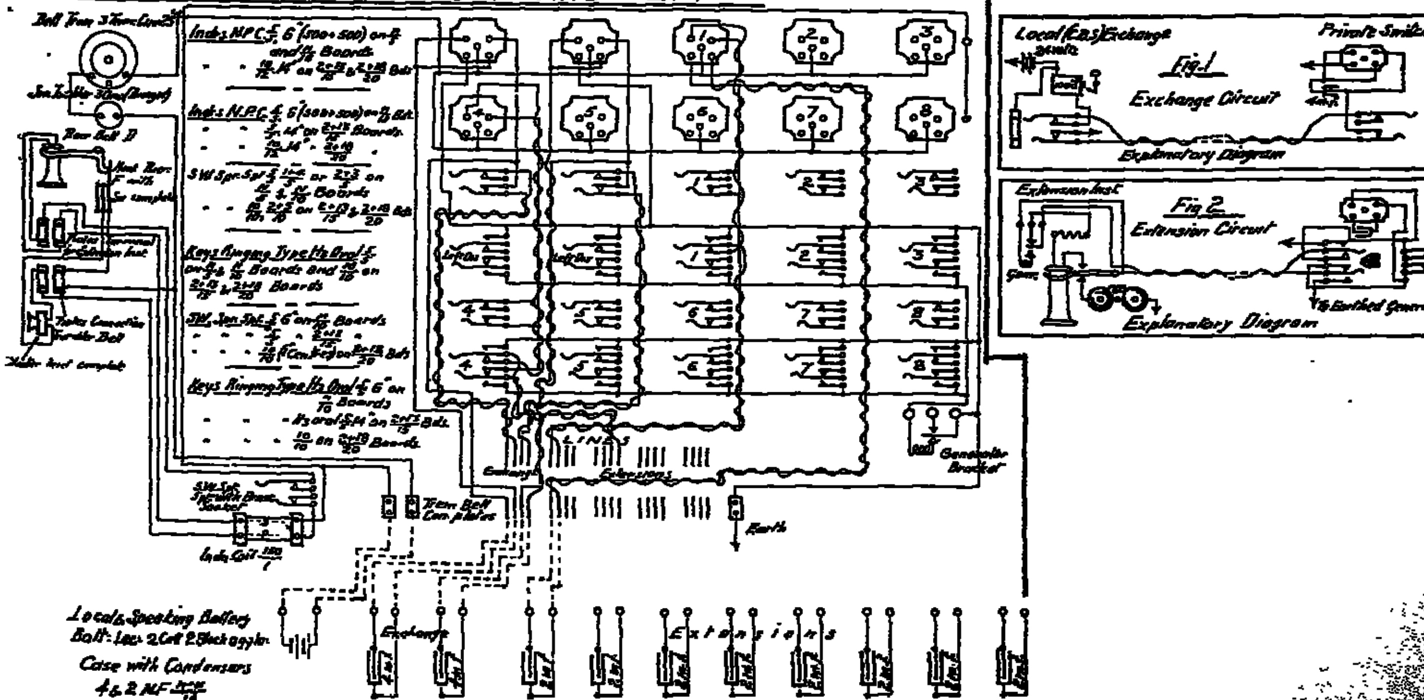


FIG. 85.

connect earth terminal to earth. Drop all Exchange indicators by ringing with earthed generator on A lines. Local bell should be switched on and ring in each case.

Operating Test.—Connect No. 1 Exchange lines to a model C.B.S. Exchange. Insert operator's plug in Exchange jack and call Exchange by lifting operator's receiver. Speak to Exchange through 30 miles of artificial standard cable. Depress switch hook, which should cut off speech. Clear by removing plug from Exchange jack. The Exchange indicator on the board should not operate. Repeat for all Exchange lines. Connect No. 1 extension lines to a C.B.S. telephone (telephone No. 11). Drop the calling indicator by ringing with the extension generator. Switch the local bell on. Plug extension jack No. 1 to operator's jack and speak to and ring extension. Repeat for all extension lines, using all cords in turn.

The following switchboards, which are some of the late National Telephone Company's types, are still largely used, and the letters "N.T." after the titles indicate this fact.

Switchboards, Wall Pattern, Cordless, N.T.

Fig. 86 is a wiring diagram.

	Figure of Merit Currents. Milliamperes.
Indicator 200A	10 (coils in series).
„ 200B	6 („ „).

(For Table see p. 251.)

Insulation Test (100-volt megger).—All plugs in bottom row. Test each pair of line terminals against all other pairs of line terminals and frame of corresponding indicator. Test extension line terminals against earth; receiver terminals against cradle; primary of induction coil against secondary and bell coils against frame. Remove all plugs from switchboard. Test each pair of line terminals against the corresponding indicator tags, and the tip of each plug against the sleeve. Minimum insulation, 1 megohm.

Continuity Test with Low Resistance Buzzer of Combination Testing Set.—Connect the testing leads to No. 1 line terminals. Plug in jack 1-2, using No. 1 plug, and short circuit No. 2 line terminals. The buzzer should operate. Repeat for all No. 1 line connections. Transfer the testing leads to the other line terminals in turn, and repeat the tests using the corresponding plug proper to each line.

Ringing Test, Cradle Down.—Plug in bottom row of jacks. Connect a 2-volt battery to M.B. terminals and put plug in left-hand hole of plug switch. Ring in on each line with full generator, and also with 5000 ohms in series. The line indicator and night bell should operate in each case. Plug in service jacks. Ring in on each line with full generator and also with 20,000 ohms in series. The Exchange magneto bell should ring. Ring out on each line with the switchboard generator, Combination testing set bell should ring with resistance of 30,000 ohms in series.

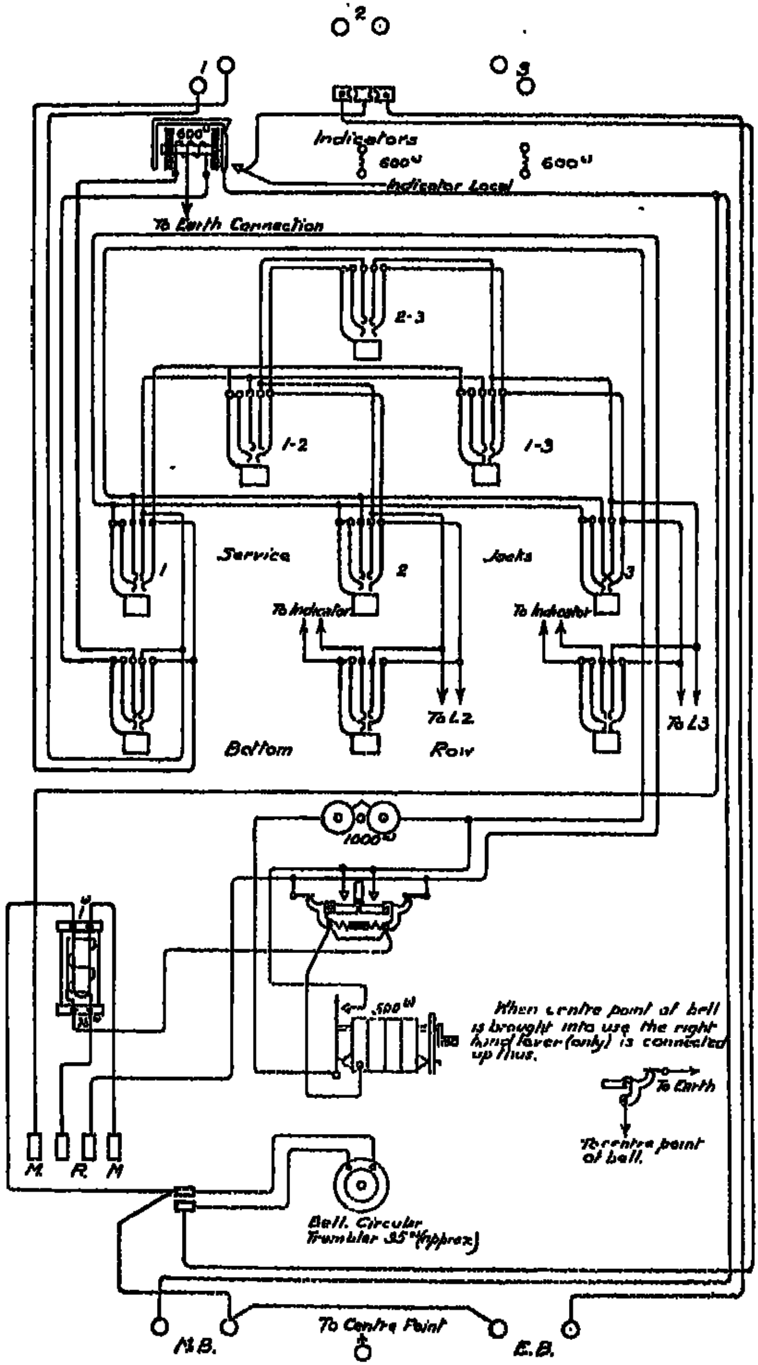


FIG. 86.—Switchboard W.P. Cordless N.T.

RESISTANCE TESTS.

Testing Leads Connected to.	Other Connections to be Made.	Resistance Ohms.	Apparatus in Circuit.
A and B tags of each line.	All plugs in bottom row.	600 or 1000, depending on type of indicator fitted.	Indicator coils in series.
Exchange A line and earth; Exchange B line and earth.	Do.	300 or 500.	Indicator one coil.
A and B tags of any line.	Plug in corresponding service jack. Cradle down.	1000	Magneto bell.
A tag of any line and earth; B tag of any line and earth.	Do.	500	Magneto bell (one coil) when centre point is earthed.
A and B tags of any line.	Do., and cut out of generator operated.	500	Generator.
Do.	Plug in service jack; cradle up; receiver short circuited.	25	Secondary of induction coil.
M.B. terminals.	M. terminals of transmitter short circuited.	1	Primary of induction coil.
Do.	Plug in left-hand hole of plug switch. Any indidicator shutter operated.	35	Trembler bell.
Do.	Plug in right-hand hole of plug switch; E.B. terminals short circuited; any indicator operated.	Short circuit.	E.B. circuit.

Speaking Test.—Plug in service jacks, and 2-volt battery on M.B. terminals. Cradle up. Connect up a telephone No. 28 (hand micro-telephone), speak to model Exchange through 30 miles of artificial standard cable, using each line in turn.

SWITCHBOARDS, WALL PATTERN, SINGLE CORD, N.T., NOS. 1-7.

Figure of Merit Current.—1000-ohm indicator, 6 milliamperes. Fig. 87 shows the connections.

Resistance Test.—Testing leads connected to top left-hand terminal and middle bottom terminal of each line, 1000 ohms. Apparatus in circuit line and clearing indicators.

Insulation Test (100-volt megger).—Using a spare plug and cord plug in each jack in turn, and test between tip and sleeve

conductors. Test between tip and sleeve of all plugs and between frame of indicator mounting and sleeve of each plug. The insulation resistance should be not less than 1 megohm.

Continuity Test, Fig. 1 (Fig. 87) (using low resistance buzzer of Combination testing set).—Test each line between—

Top left terminal and sleeve of plug.
Bottom right terminal and tip of plug.
Bottom left terminal and top right terminal.

Insert a spare plug (with cord) in each line jack and test between—

Top left terminal and sleeve conductor of spare plug.
Top right terminal and tip conductor of spare plug.

Fig. 1.

Fig. 2.

Fig.

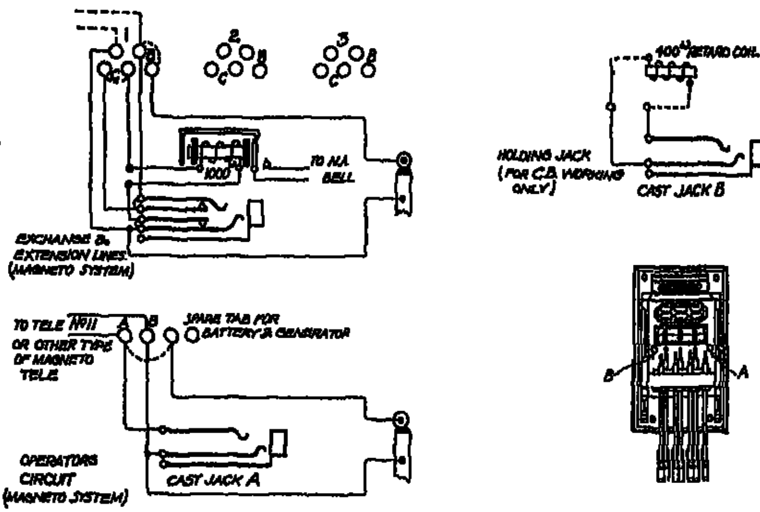


Fig. 87.—Switchboard W.P. Single Cord N.T., Nos. 1-7.

Fig. 2 (Fig. 87).—Test between second terminal and sleeve of A plug (operator's circuit).

Test between third terminal and tip of A plug.

Insert a spare plug (with cord) in cast jack A, and test between

First terminal and tip conductor of spare plug.
Second terminal and sleeve conductor of spare plug.

Fig. 3 (Fig. 87).—Insert a spare plug (with cord) in cast jack B and test between—

First terminal and sleeve conductor of spare plug.
Second terminal and tip conductor of spare plug.

Ringing Test.—Drop the shutters of all line indicators by ringing-in on top left terminal and middle bottom terminal (*a*) with full generator, and (*b*) through 5000 ohms. Low resistance buzzer

should be connected to the night bell terminals and operate after each shutter drops. Using a spare plug and cord, plug in each jack in turn and ring on the tip and sleeve conductors after short circuiting the top right terminal and middle bottom terminal. The indicator should operate.

Each plug should be inserted into every jack to ascertain that it is a good fit. It is essential that the line terminals should be connected to the jack springs as shown in the diagram, because if the wires on the inner and outer springs are transposed, the board, if required, will not work if the short connections between the springs are cut.

SWITCHBOARDS, WALL PATTERN, DOUBLE CORD, N.T., Nos. 19, 20, AND 21.

Fig. 88 is a diagram of the connections.

	Figure of Merit Currents. Milliamperes.
Indicator N.T. No. 11 . . .	6
Indicator No. 1400A . . .	25
Indicator N.T. No. 10 . . .	6

RESISTANCE TESTS.

Circuit.	Testing Leads Connected to	Resistance Ohms.	Apparatus in Circuit.
Exchange	A and B tags	1000	Exchange indicators
„	A and earth tags	500	„ „ one coil
„	B and earth tags	500	„ „ other coil
Extension	A and B tags	100	Extension indicators
Cord	Tip and sleeve of each plug (keys normal)	1000	Clearing indicators

Insulation Test (100-volt megger).—Keys normal. Test between each pair of plugs—tip and sleeve—and all other pairs of plugs; night bell terminals and all line terminals and plugs; telephone terminals and key frames and tip and sleeve of all plugs. Speaking keys thrown (away from operator). Test between tip and sleeve of each plug.

Continuity Test.—Connect low resistance buzzer of Combination testing set. Speaking keys thrown (towards operator). Test between—

Tips of front plugs and telephone terminal No. 1.
Sleeves of front plugs and telephone terminal No. 2.

Speaking keys thrown (away from operator). Test between—

Tips of back plugs and telephone terminal No. 1.
Sleeves of back plugs and telephone terminal No. 2.

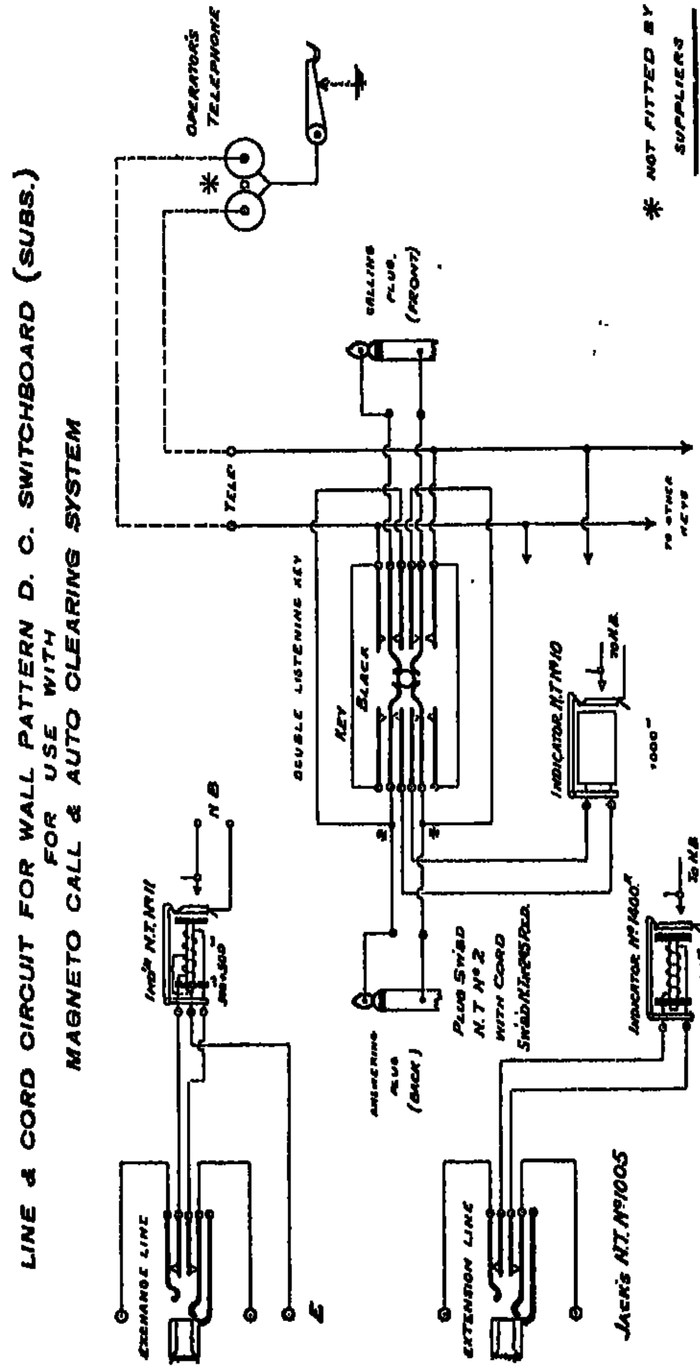


Fig. 88.—Switchboard W.P. Double Cord N.T., Nos. 19, 20, and 21. Diagrams of Connections.

Keys normal. Test between—

Tips of front plugs and tips of back plugs.
Sleeves of front plugs and sleeves of back plugs.

Insert No. 1 back plug in No. 1 jack, and test between No. 1 A line tag and tip of No. 1 front plug, and between No. 1 B line tag and sleeve of No. 1 front plug. Shake cords and plugs to test for cutting-off. Repeat for all cord circuits. Insert No. 1 back plug in No. 2 jack and test between No. 2 A line tag and tip of No. 1 front plug, and between No. 2 B line tag and sleeve of No. 1 front plug. Repeat for all lines.

Ringing Test.—Drop the shutter of each Exchange line indicator by ringing-in on the A and B line tags (*a*) with full generator, and (*b*) through 5000 ohms. Connect low resistance buzzer of the Combination testing set to the night bell terminals. The buzzer should operate after each shutter drops.

The foregoing test should be repeated on each extension line, except that a series resistance of 2500 instead of 5000 ohms should be used.

With the keys normal insert one plug of each pair in a line jack and drop the clearing indicator by ringing-in on the line terminals (*a*) with full generator, and (*b*) through 5000 ohms.

SWITCHBOARDS, WALL PATTERN, DOUBLE CORD, N.T., NOS. 22 AND 23.

Fig. 89 is a diagram of the connections and colour scheme.

	Figure of Merit Currents. Milliamperes.
Line indicator	25
Clearing indicator	6

RESISTANCE TESTS.

Circuit.	Testing Leads Connected to.	Other Connections to be Made.	Resistance Ohms.	Apparatus in Circuit.
Subscriber's line.	A and B tags.	*Nil.*	100	Line indicators.
Cord.	Tip and sleeve of plugs.	Keys normal.	1000	Clearing indicators.
"	Battery tags.	Short circuit outside tags of operator's jack.	1	Primary of induction coil.
"	Tip and sleeve of any plug.	Short circuit inside springs of operator's jack and operate listening key.	25	Secondary of induction coil.

Insulation Test (100-volt megger).—Keys normal. Test between each pair of plugs—tip and sleeve—and all other pairs of plugs;

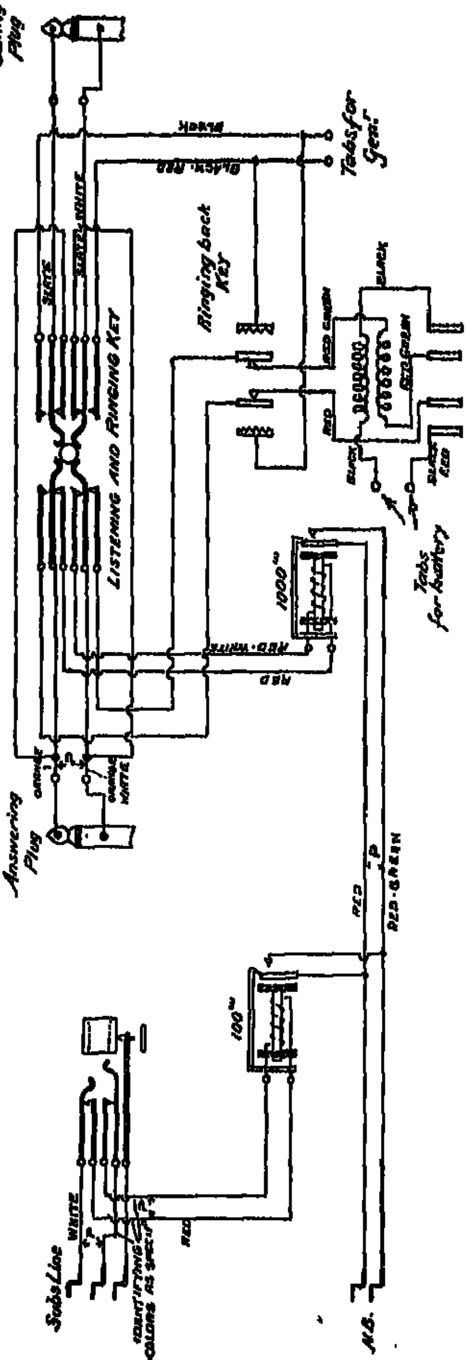


FIG. 89.—Switchboard W.P. Double Cord N.T., Nos. 22 and 23. Diagram of Line and Cord Circuits.

night bell terminals and all line terminals and plugs; generator terminals and each pair of plugs, frames of keys, and inner springs of instrument jack. Frames of keys and inner springs of instrument jack, and third and fourth springs of instrument jack.

Listening key operated; test between tip and sleeve of each pair of plugs. The insulation resistance should be not less than 1 megohm.

Continuity Test.—Connect low resistance buzzer of Combination testing set to testing leads. Keys normal. Test between tip of answering plug and tip of calling plug; sleeve of answering plug and sleeve of calling plug.

Insert answering plug in No. 1 jack and test between—

No. 1 A line tag and tip of calling plug.
No. 1 B line tag and sleeve of calling plug.

Shake cords and plugs while testing to detect any cutting-off, and repeat for all cord circuits. Insert No. 1 answering plug in No. 2 line jack and test between—

No. 2 A line tag and tip of calling plug.
No. 2 B line tag and sleeve of calling plug.

Repeat for all lines. Test between socket of line jacks and corresponding line tags.

Ringing Test.—Drop the shutter of each line indicator by ringing in on A and B line tags (*a*) with full generator; (*b*) with 2500 ohms in series. Connect low resistance buzzer of Combination testing set to night bell terminals. Buzzer should operate after each shutter drops.

With the keys normal insert one plug of each pair in a line jack and drop the clearing indicator shutter by ringing-in on the line tags (*a*) with full generator; (*b*) through 5000 ohms. Connect testing leads with generator and bell in series (Combination testing set) to generator tags on the board. Short circuit the A and B tags of any line. Insert each calling plug in turn in the corresponding line jack and operate the ringing key. The testing set bell should ring. Operate the listening key and the ring-back key. The testing set bell should ring in this case when each answering and each calling plug is inserted in the jack.

Speaking Test.—Connect a 2-volt battery to battery tags. Join up a telephone No. 28 (hand micro-telephone) and speak to a model Exchange through 30 miles of artificial standard cable, using each plug in turn.

CHAPTER XV

MEASUREMENTS MADE AT AUDIO FREQUENCIES. BALANCED RELAYS AND RETARDATION COILS. REPEATING COILS

ALTERNATING current measurements at speech frequencies are made on certain types of apparatus by means of a Wheatstone Bridge provided with special non-reactive resistances. The following is a brief description of the theory of the methods employed. It is usual to arrange for the current employed to be a simple sine function of the time, viz., $I = I_0 \sin \omega t$ where I is the value at the time t in seconds, reckoned from zero, I_0 the maximum value, and ω the angular velocity in radians per second—$\omega = 2\pi n$ where n is the frequency. It is assumed that the measurements are made after the initial rush of current to charge the system has taken place, and no account is taken of the charging current in the calculations. As the quantities to be dealt with take account of direction as well as magnitude, that is to say, they are vectors, it will be advisable to begin by considering the following equation:

FIG. 90.

$$A = a \sin \omega t + b \cos \omega t.$$

Multiply and divide by $\sqrt{a^2 + b^2}$, then

$$A = \sqrt{a^2 + b^2}\left(\frac{a}{\sqrt{a^2 + b^2}} \sin \omega t + \frac{b}{\sqrt{a^2 + b^2}} \cos \omega t\right),$$

and from Fig. 90 this is seen to be

$$\begin{aligned} A &= \sqrt{a^2 + b^2}\,(\sin \omega t \cos \phi + \cos \omega t \sin \phi) \\ &= \sqrt{a^2 + b^2} \sin (\omega t + \phi) = \sqrt{a^2 + b^2} \sin \left(\omega t + \tan^{-1} \frac{b}{a}\right). \end{aligned}$$

$\sqrt{a^2 + b^2}$ is the size of the vector or modulus and the angle ϕ, which is usually written $\tan^{-1} \frac{b}{a}$ determines the direction of the vector.

If a circuit contain capacity only, say, a condenser, the current at any instant t during the time of charging may be written—

$$I = \frac{dQ}{dt} = C\frac{dV}{dt}$$

where Q is the quantity in coulombs, C the capacity in farads, V the

potential in volts, and I the instantaneous current in amperes. It is convenient in making the calculations to write θ for $\frac{d}{dt}$ so that

$$I = C\frac{dV}{dt} = C\theta V = \frac{V}{\frac{1}{C\theta}}.$$

Similarly, for a circuit containing resistance and inductance in series, we have

$$V = RI + L\frac{dI}{dt} = I(R + L\theta),$$

and for a circuit containing resistance, inductance, and capacity in series,

$$\frac{V}{I} = R + L\theta + \frac{1}{C\theta},$$

or

$$I = \frac{V}{R + L\theta + \frac{1}{C\theta}}.$$

In dealing with vector quantities, it is allowable to add algebraically the horizontal and vertical components, and those which will be met with in this brief description of the theory are dealt with in the following manner. Consider the equation

$$I = I_0 \sin \omega t \quad . \quad . \quad . \quad . \quad (1)$$

Differentiating, we have

$$\frac{dI}{dt} = \theta I = \omega I_0 \cos \omega t \quad . \quad . \quad . \quad (2)$$

and since the angle ωt is the same in the two equations (1) and (2), we see that θI is at right angles to I, and the amplitude I_0 is multiplied by ω. If we differentiate a second time, we have

$$\frac{d^2I}{dt^2} = \theta^2 I = -\omega^2 I_0 \sin \omega t.$$

$\theta^2 I$, therefore, is in the opposite direction to I, and at right angles to θI. The amplitude I_0 is multiplied by ω^2. Differentiating a third time we have

$$\frac{d^3I}{dt^3} = \theta^3 I = -\omega^3 I_0 \cos \omega t.$$

$\theta^3 I$ is in the opposite direction to θI, and at right angles to I and $\theta^2 I$. The amplitude I_0 is multiplied by ω^3. Differentiating a fourth time we have

$$\frac{d^4I}{dt^4} = \theta^4 I = \omega^4 I_0 \sin \omega t.$$

$\theta^4 I$ is in the same direction as I, but its amplitude I_0 is multiplied by ω^4. If these relationships are borne in mind, θ may be treated algebraically as an ordinary term with certain precautions, which will appear in the following examples.

The frequency of an alternating current at speech frequencies can be measured by the following method (Fig. 91), where RL represents an adjustable inductometer; C an adjustable air condenser—in the case referred to later it was a good mica condenser and R_3 was an ordinary double-wound resistance box—and R_1 and R_2 non-reactive resistances. A non-reactive resistance is one in which the distributed capacity is balanced by the distributed inductance, and which behaves at any speech frequency as a pure resistance.

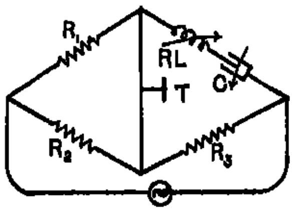


FIG. 91.

Alternating current of sine form is supplied to the bridge and balance is obtained by adjusting the capacity and the resistance R_3 for a given position of the inductometer until there is no sound in the telephone receiver T; R_1 and R_2 were equal, being 100 ohms each. When balance is obtained we have

$$\frac{R_1}{R_2} = \frac{R + L\theta + \frac{1}{C\theta}}{R_3}.$$

$$\therefore \frac{R_1 R_3}{R_2} = \frac{RC\theta + LC\theta^2 + 1}{C\theta} = R_3 \text{ since } R_1 = R_2.$$

Apply $I_0 \sin \omega t$ to both sides, then

$$R_3 I_0 \sin \omega t = \frac{I_0 \sin \omega t(RC\theta + LC\theta^2 + 1)}{C\theta}$$

$$= \frac{I_0 \sqrt{(1 - \omega^2 LC)^2 + R^2C^2\omega^2} \sin\left(\omega t + \tan^{-1}\frac{RC\omega}{1 - \omega^2 LC} - \tan^{-1}\frac{C\omega}{0}\right)}{\sqrt{C^2\omega^2}},$$

which reduces to

$$R_3 = R \text{ if } (1 - \omega^2 LC) = 0,$$

which will be shown to be the case after the method of arriving at this result has been briefly explained.

The method of writing down this result is based upon a device which will be found fully described in Professor Perry's "Calculus for Engineers." Consider the fraction

$$\frac{a + b\theta + c\theta^2 + d\theta^3 + e\theta^4 + \text{etc.}}{a + \beta\theta + \gamma\theta^2 + \delta\theta^3 + \epsilon\theta^4 + \text{etc.},}$$

and apply to it $I_0 \sin \omega t$, arranging, however, that terms containing odd powers of θ are differentiated $(n - 1)$ times only where n is

the index of θ, so that the numerator and denominator consist of two sets of terms, one set at right angles to the other, and consequently in a form that can be summed algebraically. Treating the above fraction in this way, we have

$$\frac{I_0 \sin \omega t(a + b\theta + c\theta^2 + d\theta^3 + e\theta^4)}{I_0 \sin \omega t(\alpha + \beta\theta + \gamma\theta^2 + \delta\theta^3 + \epsilon\theta^4)}$$
$$= \frac{I_0 \sin \omega t(a + b\theta - c\omega^2 - d\omega^2\theta + e\omega^4)}{I_0 \sin \omega t(\alpha + \beta\theta - \gamma\omega^2 - \delta\omega^2\theta + \epsilon\omega^4)} \quad . \quad . \quad (1)$$

If we assume that the algebraic addition has been made, and that

$$a - c\omega^2 + e\omega^4 = A$$

and

$$b\theta - d\omega^2\theta = B\theta,$$

we may write the numerator

$$I_0 \sin \omega t(A + B\theta) = I_0(A \sin \omega t + B\omega \cos \omega t)$$
$$= I_0 \sqrt{A^2 + B^2\omega^2}\left(\frac{A}{\sqrt{A^2 + B^2\omega^2}} \sin \omega t + \frac{B\omega}{\sqrt{A^2 + B^2\omega^2}} \cos \omega t\right)$$
$$= I_0 \sqrt{A^2 + B^2\omega^2} \sin\left(\omega t + \tan^{-1}\frac{B\omega}{A}\right) = I_0 \sqrt{A^2 + B^2\omega^2} \sin(\omega t + \epsilon)$$

where ϵ is an angle whose tangent is $\frac{B\omega}{A}$.

Similarly for the denominator we have

$$\alpha - \gamma\omega^2 + \epsilon\omega^4 = C$$
$$\beta\theta - \delta\omega^2\theta = D\theta$$

so that we may write the denominator

$$I_0 \sin \omega t(C + D\theta).$$

For the purposes of our discussion we no longer want $I_0 \sin \omega t$ in the denominator, because we assume in these equations that $I_0 \sin \omega t$ is applied to a fraction of the form $\frac{A + B\theta}{C + D\theta}$.

We have to consider, therefore, the effect of applying

$$I_0 \sqrt{A^2 + B^2\omega^2} \sin (\omega t + \epsilon)$$

to $\frac{1}{C + D\theta}$. It is convenient to clear the denominator of θ by multiplying numerator and denominator by $(C - D\theta)$, thus $(C + D\theta)(C - D\theta) = C^2 + D^2\omega^2$.

$(C + D\theta)$ and $(C - D\theta)$ are conjugate expressions, and when either occurs as the denominator of a fraction it may be cleared of θ by multiplying by the other. Hence

$$\frac{I_0\sqrt{A^2+B^2\omega^2}\sin(\omega t+\epsilon)}{C+D\theta}=\frac{I_0\sqrt{A^2+B^2\omega^2}\sin(\omega t+\epsilon)(C-D\theta)}{C^2+D^2\omega^2}$$

$$=\frac{I_0\sqrt{A^2+B^2\omega^2}\sqrt{C^2+D^2\omega^2}\left(\sin(\omega t+\epsilon)\frac{C}{\sqrt{C^2+D^2\omega^2}}-\cos(\omega t+\epsilon)\frac{D\omega}{\sqrt{C^2+D^2\omega^2}}\right)}{C^2+D^2\omega^2}$$

$$=\frac{I_0\sqrt{A^2+B^2\omega^2}(\sin(\omega t+\epsilon)\cos\phi-\cos(\omega t+\epsilon)\sin\phi)}{\sqrt{C^2+D^2\omega^2}}$$

where ϕ is an angle whose tangent is $\frac{D\omega}{C}$.

$$\therefore \frac{I_0\sqrt{A^2+B^2\omega^2}\sin(\omega t+\epsilon)}{C+D\theta}$$

$$=\frac{I_0\sqrt{A^2+B^2\omega^2}\sin(\omega t+\epsilon-\phi)}{\sqrt{C^2+D^2\omega^2}}$$

$$=\frac{I_0\sqrt{A^2+B^2\omega^2}\sin\left(\omega t+\tan^{-1}\frac{B\omega}{A}-\tan^{-1}\frac{D\omega}{C}\right)}{\sqrt{C^2+D^2\omega^2}}$$

$$=\frac{I_0\sin\omega t(A+B\theta)}{C+D\theta}.$$

We may regard this as a pattern equation. If we compare

$$\frac{I_0\sin\omega t(A+B\theta)}{C+D\theta}$$

with

$$\frac{I_0\sin\omega t\,(1+LC\theta^2+RC\theta)}{C\theta},$$

we notice that A corresponds in $(A+B\theta)$ to $1+LC\theta^2$ in

$$\frac{1+LC\theta^2+RC\theta}{C\theta}.$$

$1+LC\theta^2$ may be written as $1-\omega^2LC$. Similarly, we notice that in $\frac{(1-\omega^2LC)+RC\theta}{C\theta}$ there is no term corresponding to C in the denominator of $\frac{A+B\theta}{C+D\theta}$, therefore we are entitled to write nought in the denominator of $\frac{(1-\omega^2LC)+RC\theta}{C\theta}$, that is

$$\frac{(1-\omega^2LC)+RC\theta}{O+C\theta}.$$

Comparing this with the pattern equation, we must insert O for C and obtain

$$\frac{I_0\sin\omega t(A+B\theta)}{O+D\theta}=\frac{I_0\sqrt{A^2+B^2\omega^2}\sin\left(\omega t+\tan^{-}\frac{B\omega}{A}-\frac{\pi}{2}\right)}{\sqrt{O+D^2\omega^2}}$$

since $\tan^{-1}\frac{D\omega}{O} = \tan^{-1}$ infinity or 90°. In order that the application of $I_0 \sin \omega t$ to $\frac{A + B\theta}{C + D\theta}$ shall make no difference in the phase angle, $\tan^{-1}\frac{B\omega}{A}$ must become $\tan^{-1}\frac{B\omega}{O}$, similar to the case of $\tan^{-1}\frac{D\omega}{C}$. Comparing these results with the original equation, viz.,

$$R_3 = \frac{1 + LC\theta^2 + RC\theta}{C\theta} = \frac{(1 - \omega^2 LC) + RC\theta}{O + C\theta},$$

$\therefore R_3 I_0 \sin \omega t$

$$= \frac{I_0\sqrt{(1-\omega^2LC)^2 + R^2C^2\omega^2}}{\sqrt{C^2\omega^2}}\sin\left(\omega t + \tan^{-1}\frac{RC\omega}{1-\omega^2LC} - \tan^{-1}\frac{C\omega}{O}\right)$$

$$= \frac{I_0\sqrt{(1 - \omega^2LC)^2 + R^2C^2\omega^2}}{\sqrt{C^2\omega^2}}\sin\left(\omega t + \tan^{-1}\frac{RC\omega}{1 - \omega^2LC} - \frac{\pi}{2}\right).$$

Hence, if $\frac{RC\omega}{1 - \omega^2LC}$ is to be equal to infinity $\left(\tan\frac{\pi}{2} = \infty\right)$ then $1 - \omega^2LC$ must be zero or $1 - \omega^2LC = 0$. When this is the case, we have

$$R_3 I_0 \sin \omega t = \frac{I_0 \sin \omega t\sqrt{O^2 + R^2C^2\omega^2}}{\sqrt{C^2\omega^2}}$$

$$R_3 = \frac{\sqrt{R^2C^2\omega^2}}{\sqrt{C^2\omega^2}}$$

$\therefore R_3 = R$, and the current is in phase with the volts.

$1 - \omega^2LC = 0$ may be written $\omega L = \frac{1}{\omega C}$ from which it is seen that at this frequency the product of angular velocity and inductance is equal to the reciprocal of the product of angular velocity and capacity. This is the condition for resonance in a simple circuit.

In an actual experiment the following values were used :—

$$R_1 = R_2 = 100 \text{ ohms}$$
$$R_3 = 53{\cdot}3 \text{ ohms}$$
$$L = {\cdot}1165 \text{ henries}$$
$$C = {\cdot}3393 \text{ mfd.}$$

$$\omega^2 = \frac{1}{LC} = (2\pi n)^2$$

$$\therefore n = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{{\cdot}1165 \times {\cdot}3393 \times 10^{-6}}} = 798{\cdot}7.$$

A further experiment was made, and consisted of the same inductometer and condenser in the third arm of the bridge, but arranged in parallel, as shown in Fig. 92.

In the third arm of the bridge there are two paths for the current, one through RL and the other through C, and the joint impedance may be found by the ordinary rule for pure resistances, that is,

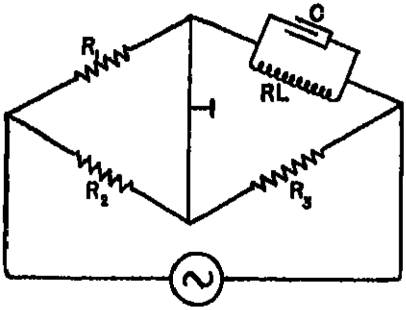


FIG. 92.

$$\frac{(R + L\theta)\frac{1}{C\theta}}{(R + L\theta) + \frac{1}{C\theta}}.$$

When balance is obtained we have

$$\frac{R_1}{R_2} = \frac{\dfrac{(R + L\theta)\frac{1}{C\theta}}{(R + L\theta) + \frac{1}{C\theta}}}{R_3}$$

$$\therefore \frac{R_3R_1}{R_2} = \frac{R + L\theta}{RC\theta + LC\theta^2 + 1}$$

R_1 was made equal to R_2.

$$\therefore R_3 I_0 \sin \omega t$$

$$= \frac{I_0\sqrt{R^2 + \omega^2L^2}}{\sqrt{(1 - \omega^2LC)^2 + R^2C^2\omega^2}} \sin\left(\omega t + \tan^{-1}\frac{\omega L}{R} - \tan^{-1}\frac{RC\omega}{(1 - \omega^2LC)}\right).$$

The readings were

$$\begin{aligned} R_3 &= 6469 \text{ ohms} \\ L &= \cdot 1165 \text{ Henries} \\ C &= \cdot 3393 \text{ mfd.} \end{aligned} \Bigg\} \text{as in the previous test.}$$

R_3 was not a specially made non-reactive resistance, but was of the ordinary double-wound type. This fact is of interest because if we calculate the value of R_3 from the value of $\dfrac{\sqrt{R^2 + \omega^2L^2}}{\sqrt{(1 - \omega^2LC)^2 + R^2C^2\omega^2}}$ assuming that the value of R found in the previous test, viz., 53·3 ohms, is correct, and that $1 - \omega^2LC = 0$, we get

$$\frac{\sqrt{R^2 + \omega^2L^2}}{\sqrt{\omega^2C^2R^2}} = \frac{\sqrt{(53\cdot 3)^2 + (5029)^2(\cdot 1165)^2}}{(5029)(\cdot 3393 \times 10^{-6})(53\cdot 3)} = 6443 \text{ ohms},$$

which is smaller than the value found, viz., 6469 ohms. This points to there being a distributed capacity in the resistance, which we proceed to investigate as follows. We have two angles whose tangents are given as

$$\frac{\omega CR}{1 - \omega^2LC} \text{ and } \frac{\omega L}{R}.$$

We have assumed that $1 - \omega^2 LC = 0$, therefore the first angle is 90° or $\frac{\pi}{2}$.

$$\frac{\omega L}{R} = \frac{5029 \times \cdot 1165}{53\cdot 3} = 11.$$

The angle whose tangent is 11 is 84° 47′. If we subtract this from $\frac{\pi}{2}$ we get 5° 13′ as the angle of the resistance, which we know is due to the capacity of the windings. Assuming that the resistance and capacity in the windings are in parallel, we have

$$\frac{V}{I} = \frac{R\frac{1}{C\theta}}{R + \frac{1}{C\theta}} = \frac{R}{1 + RC\theta} = \frac{R(1 - RC\theta)}{1 + R^2C^2\omega^2}.$$

$$\therefore V = \frac{RI_0 \sin(\omega t - \tan^{-1} RC\omega)}{\sqrt{1 + R^2C^2\omega}}$$

R we measured as $R_s = 6469$ ohms, and $\omega = 5029$, therefore

$$RC\omega = \tan 5° 13' = \cdot 0913$$

and

$$C = \frac{\cdot 0913}{5029 \times 6469} = \cdot 00281 \text{ mfd.}$$

The modulus of the previous equation is

$$\frac{R}{\sqrt{1 + R^2C^2\omega^2}} = \frac{6469}{\sqrt{1 + (6469)^2(\cdot 00281)^2 \times 10^{-12} \times (5029)^2}}$$
$$= \frac{6469}{1\cdot 004} = 6443 \text{ ohms,}$$

which agrees with the value found from the modulus $\frac{\sqrt{R^2 + \omega^2 L^2}}{\sqrt{\omega^2 C^2 R^2}}$ and confirms the assumption that the resistance 6469 is shunted by a capacity 0·00281 mfd.

It is important to remember that an ordinary double-wound resistance generally contains a small distributed capacity, and for this reason where pure non-reactive resistances are necessary they have to be specially made for the purpose. Most of the non-reactive resistances in use in the Post Office were made by Messrs. Sullivan. Since the introduction of the thermionic valve type of telephone repeater, it has been necessary to select large numbers of paper condensers for use in the balancing network of cables, and these condensers have to be measured at 800 periods per second for inductive capacity and leakage resistance. The bridge method shown in Fig. 91, where the capacity is balanced in series with an

inductometer, has proved convenient for the purpose, the capacity being calculated from the formula already obtained, namely,

$$C = \frac{1}{(2\pi n)^2 L}.$$

In the balance in series on page 263, R_3 was 53·3 ohms, and this was the resistance required to balance the effective resistance of the inductometer. The latter, however, consisted of an inductance coil of the fixed value of 110 millihenries, and an effective resistance of 41 ohms, and an adjustable inductometer which at the value used, viz., 6·5 millihenries, had an effective resistance of 12·3 ohms, and the sum of these two, 41 + 12·3, agrees with the value found. It was evident, therefore, that the leakage resistance of the mica condenser which was used was negligibly small. In the case of paper condensers, the leakage resistance is not negligibly small. The following table gives some actual values :—

Nominal Capacity.	Capacity at 800 p.p.s.	Leakage Resistance at 800 p.p.s.	Nominal Capacity.	Capacity at 800 p.p.s.	Leakage Resistance at 800 p.p.s.
mfd.	mfd.	ohms.	mfd.	mfd.	ohms.
1	0·92	1·5	0·1	0·096	13·0
1	1·06	1·5	2·0	1·92	0·5
1	1·01	2·0	2·0	1·97	2·5
0·5	0·458	2·0	2·0	2·13	0·5
0·5	0·452	3·0	2·0	1·94	0·5
0·5	0·501	1·5	4·0	3·91	1·0
0·1	0·109	10·0	4·0	4·09	0·5
0·1	0·106	7·0	4·0	3·87	1·5

Since in the formula $C = \frac{1}{(2\pi n)^2 L}$ the capacity varies inversely as the inductance, there is a limit to the use of the series inductometer method, and for paper condensers of higher capacities than, say, 2 mfd. it is preferable to use the Wien arrangement of the bridge, as shown in Fig. 93, where R_1, R_2, R_3, and R_4 are non-reactive resistances. C_1 is a good mica condenser and C_2 the paper condenser under test. For balance we have

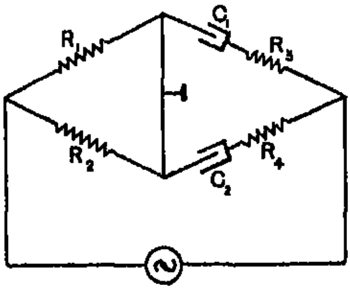


FIG. 93.

$$\frac{R_1}{R_2} = \frac{\frac{1}{C_1\theta} + R_3}{\frac{1}{C_2\theta} + R_4} = \frac{C_2\theta + R_3C_1C_2\theta^2}{C_1\theta + R_4C_1C_2\theta^2}.$$

$$\therefore R_1C_1\theta + R_1R_4C_1C_2\theta^2 = R_2C_2\theta + R_2R_3C_1C_2\theta^2.$$

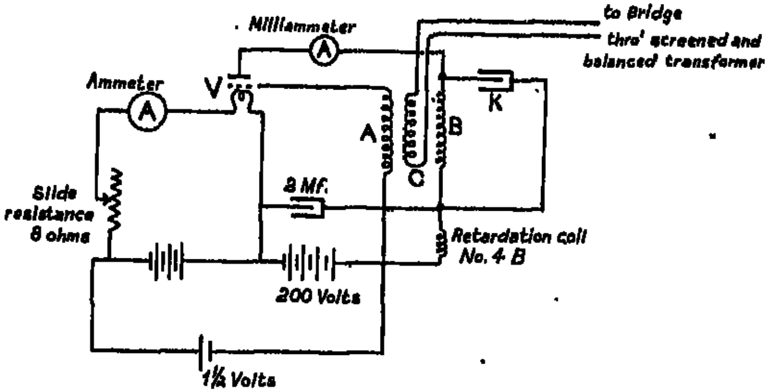


FIG. 94.—Diagram of Generating Set for Audio Frequencies.

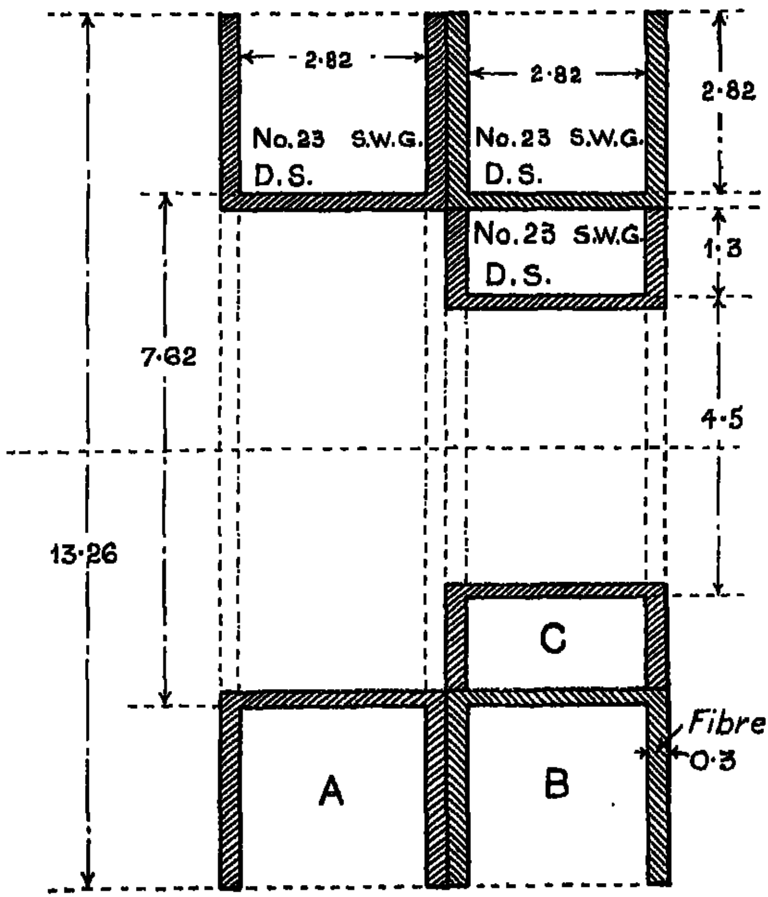


FIG. 95.—$\frac{1}{1}$ Transformer. Dimensions in Centimetres.

Equating like vectors we have

$$R_1C_1\omega = R_2C_2\omega. \quad \therefore \frac{R_1}{R_2} = \frac{C_2}{C_1}.$$

$$R_1R_4C_1C_2\omega^2 = R_2R_3C_1C_2\omega^2 \quad \therefore \frac{R_1}{R_2} = \frac{R_3}{R_4}.$$

As we are measuring the leakage resistance of the condenser C the non-reactive resistance R_4 is not required, its place being take by the leakage resistance, viz.,

$$R_4 \text{ (leakage resistance)} = \frac{R_2R_3}{R_1},$$

$$C_2 \text{ (capacity)} = \frac{R_1}{R_2}C_1.$$

In the series inductometer method the known effective resistanc of the inductometer must be subtracted from the value found fc R_3 (see Fig. 80), to obtain the leakage resistance of the condenser.

Fig. 94 is a diagram of a generating set for audio frequencie

V is an oscillation thermionic valve, A and B are the coils of the

transformer, each coil of which is wound for 250 millihenries an 28 ohms, and coil C is 7·5 ohms (the details of these coils are show in Fig. 95). K = ·15 mfd. for 800 p.p.s. The 2 mfd. condenser an retardation coil, type 4B, are added to the circuit, so that the valv generator may be used on two different tests at the same tir without interference. The type of valve used is " Valve thermion No. 1," according to Post Office description, and is made by tl Marconi Company.

Balanced Relays and Retardation Coils.—In the cord circu of the Stone system a retardation coil in one line is required balance a relay in the other line, and consequently special tests a necessary in this and similar cases to ascertain that the balanc combinations—the relays and retardation coil are mounted on tl same strip and never separated—satisfy the specification in th respect. The impedance at 800 periods per second and the ang are measured, the specified values being as given in table on opposi page.

The stipulation in the Post Office Specification with regard out of balance is as follows : " The impedance of the relay shall n differ from that of the retardation coil by more than such an amou that when an approximate sine wave, alternating P.D. of from 4 10 volts at about 800 ~, is placed across the two in series, t magnitude of the alternating vector difference of potentials acrc relay and retardation coil shall not exceed 5 per cent. of the magi tude of the total applied alternating P.D. This shall hold wh the alternating current is superposed on a direct current of appro: mately either 15 or 60 milliamperes." Fig. 96 is a diagram of t circuit devised by Mr. A. J. Aldridge, of the Research Section

Type and Number.	Minimum Impedance.	Minimum Angle.
	Ohms.	Degrees.
Relay and coil No. 5AN	4800	46
" " 6 "	4800	46
" " 8 "	2000	49*
" " 9 "	1500	50*
" " 11 "	6000	50
" " 12 "	7000	50
" " 13 "	7000	50
" " 15 "	7000	50
" " 16 "	7000	50
" " 17 "	8500	43
" " 18 "	1500	50
" " 19 "	1500	50
" " 20 "	1500	50
" " 21 "	7000	50
" " 22 "	7000	50*

Those marked * have 100 milliamperes instead of 60 milliamperes direct current in the windings when the out-of-balance noise test is made

the Engineering Department of the Post Office for carrying out the balance test.

A is a balanced and screened transformer (Messrs. Western Electric Company's type 4006A), the secondary of which is used as the ratio arms of the bridge.

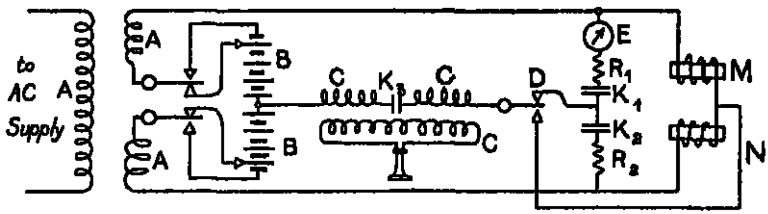


FIG. 96.—Diagram of Connections for Out of Balance Test.

B is an accumulator battery, the number of cells of which is adjusted to supply the direct current specified.

C is a high ratio transformer or induction coil of not less than 16,000 to 1000 turns, the receiver being placed across the 1000 turns.

D is a change-over key.

E is an A.C. milliammeter reading up to about 3 ma. It is used as a voltmeter in conjunction with R_1 and R_2.

K_1 and K_2 are 10 mfd. condensers.

K_3 is a 2 mfd. condenser.

R_1 and R_2 are non-inductive resistances of such values that $(R_1 + E) - R_2$ is 5 per cent. of $R_1 + E + R_2$. For 2000 ohm coils $(R_1 + E)$ should be 1900 ohms, and R_2 2100 for 6000 ohm coils, 5700 and 6300, etc.

M and N are the relay and retardation coils of the combination under test.

The test is carried out by listening on the receiver and throwin the change-over switch D (Fig. 96). In the normal position show the out of balance due to a 5 per cent. difference of P.D. is obtainec When the key is thrown the out of balance of the relay and retard tion is heard. The latter must not exceed the former. The rela and coil are provided with a common cover, designed so that the shall be no overhearing between the circuits of adjacent combin tions due to direct inductive effects between the combinations. I practice it is usual to arrange the testing circuit as shown in Fig. 9 so that the out-of-balance test can be made immediately after th relay and coil have been demagnetised, and the impedance an angle can be measured on the same set. The demagnetisation effected by applying an alternating current of approximatel sixteen periods per second at saturation value for the particul relay, and reducing the current by adding resistance until the curre is practically zero. The impedance of the coil is measured at 8c periods per second with a sine wave alternating current of 1 mill ampere—the valve generator shown in Fig. 94 is suitable for tl

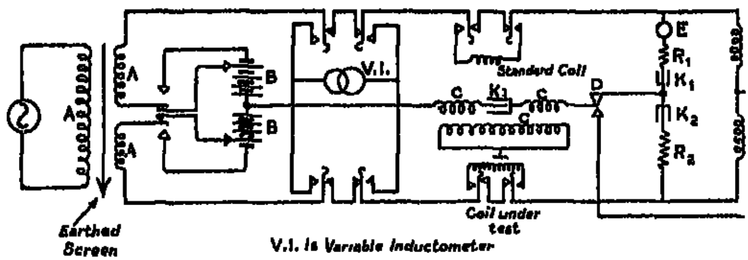


FIG. 97.—Diagram of Testing Set for Impedance and Out of Balance Tests.

purpose—and it is convenient to arrange to balance against standard coil of known, and approximately the same, impedan and general construction. The inductometer can then be switch to either arm of the bridge, whichever is required for balancing, shown in Fig. 97. It is necessary to arrange so that the movemen of the testing officer will not introduce capacity effects into t bridge arms. This is done satisfactorily by using lead-cover paper core cable for the connections wherever possible and earthi the lead covering. The metal screen between the windings of t balanced and screened transformer is earthed. A convenient instr ment for measuring the current at 800 periods per second is t Duddell thermo milliammeter, range 0 to 10 milliamperes, made the Cambridge Scientific Instrument Company.

Repeating Coils 4006A.—These coils are required to be balanc very accurately for superposed working, and consequently it necessary to apply elaborate tests to ensure that they are efficie at ringing and speech frequencies, and are satisfactorily balanc for distributed capacity, inductance, and effective resistance. T coil consists of four windings made up of two twisted pairs, o

twisted pair forming the two sections of the primary, and the other twisted pair the two sections of the secondary, the eight ends being brought out to tags numbered as shown in Fig. 98. The core is a laminated silicon steel ring.

Test No. 1.—Checking direction of windings (Fig. 99). A dry cell is connected to terminals 1 and 2, positive to 1 and negative

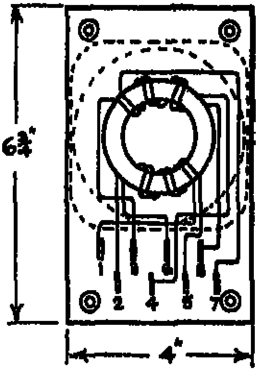


FIG. 98.

to 2, through key K. Terminals 3 and 4, 5 and 6, and 7 and 8 are connected in turn to a galvanometer G. On depressing the key the throw of the galvanometer should be in the same direction in each case. A similar test is made with the battery connected, positive to 3, negative to 4, and 1 and 2, 5 and 6, and 7 and 8 are connected in turn to the galvanometer. The throw should be in the same direction as before for all the windings.

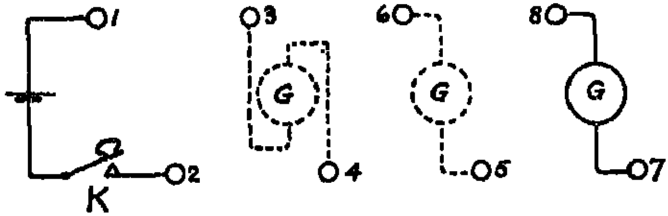


FIG. 99.

Test No. 2.—Measurement of the difference between the capacities of the two halves of the primary and secondary windings. The apparatus used is an alternating current bridge consisting of 1000 ohm non-reactive ratio arms, and two variable air condensers. Current at 800 periods per second is supplied to the bridge through a balanced and screened transformer. Before making a measurement on the repeating coils it is necessary to balance the two variable air condensers, as shown in Fig. 100. Condenser No. 1 is set in

the middle of the scale, and a balance is obtained by varying con-
denser No. 2. The bridge is then joined up as shown in Fig. 101
and balance obtained by varying condenser No. 1. The reading or

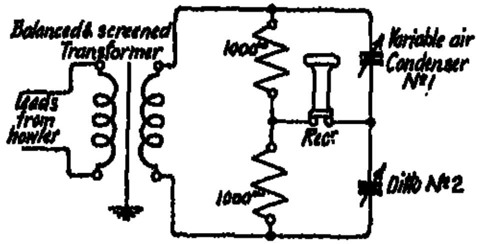


FIG. 100.

condenser No. 1 is then a measure of the out of balance of capacit
between the two halves of the primary and secondary windings
This should not exceed 30 micro-microfarads.

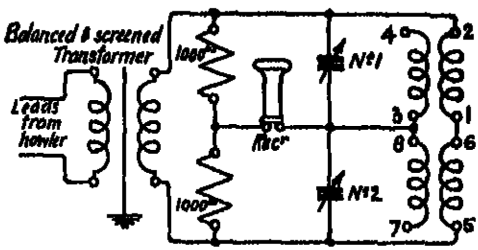


FIG. 101.

Test No. 3.—For effective resistance balance. The terminals a
connected as shown in Fig. 102. With 100·1 ohm ratio arms balan
should be obtained on the slide wire between two points 0·05 oh

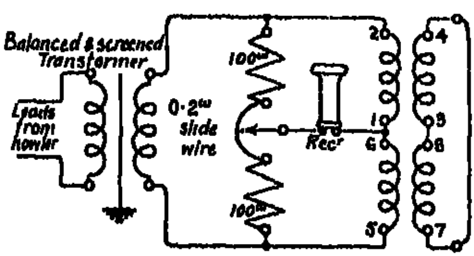


FIG. 102.

from the middle of the scale. These limits are almost equivale
to an effective resistance unbalance of 0·05 per cent., calculated
the total effective resistance.

This test should be repeated with the windings 2 and 5 a
4 and 7 interchanged.

Test No. 4.—For impedance balance. The terminals are connected as shown in Fig. 103. With 1000·1 ohm ratio arms balance should be obtained on the slide wire between two points 0·025 ohm from the middle of the scale. These limits are almost equivalent to an impedance unbalance of 0·0025 per cent. calculated on the total impedance. This test should be repeated with the windings 2 and 5 and 4 and 7 interchanged.

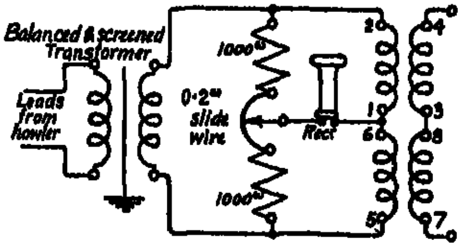


FIG. 103.

Test No. 5, for power efficiency, is made with a sine form alternating current at two frequencies, such that $2\pi n = 100$ and $2\pi n = 5000$. The test at the lower frequency is made with 80 volts impressed on the windings 2 to 1 + 6 to 5, whilst a non-reactive load of 1000 ohms is connected across the windings 4 to 3 + 8 to 7. The efficiency indicated by this test should be not less than 55 per cent. The test at the higher frequency is made under similar conditions, except that the testing current is 1 milliampere. The efficiency at the higher frequency should not be less than 80 per cent.

Test No. 6.—The direct current insulation, when tested with 100 volts between windings 2 to 1 + 6 to 5, and windings 4 to 3 + 8 to 7, and also between these windings and the iron cover, should be not less than 100 megohms.

Test No. 7.—Direct current resistance. Windings 1 to 2 and 5 to 6 should be between 28 and 34 ohms, and windings 3 to 4 and 7 to 8 between 33 and 42 ohms.

Where a large number of coils have to be tested the power efficiency test is conveniently made by comparison with a standard repeating coil of known efficiency. The test is made by comparing the secondary current in the coil under test with that in the standard coil (*a*) with the two primaries, viz., standard coil primary and primary of coil under test, in parallel; and (*b*) with the two primaries in series. For the low frequency test a ringing generator of the correct voltage and frequency is used as a source of power. Fig. 104 is a theoretical diagram of the connections for the test at low frequency, the primaries P_1P_2 joined in parallel. $R_1 = R_1$ are the 1000 ohm non-reactive resistances used as loads on the secondaries S_1S_2. T.M. is a thermo-milliammeter shunted with a suitable resistance S to reduce the current through the milliammeter to a value suitable

for the instrument. G is a resistance equal to that of the thermo-milliammeter, and is shunted by a resistance S equal to the thermo-milliammeter shunt. D_1 and D_2 are rheostats for regulating the voltage across the coils. The reading A on T.M. is noted S_1 being the secondary of the standard coil. By suitable keys, as shown in Fig. 105, T.M. and G are transposed, and the reading B for the coil under test is noted. If E is the known efficiency of the standard, then the efficiency of the coil under test may be taken as $\frac{EB}{A}$ The primaries P_1 and P_2 are next connected in series, the secondaries remaining unchanged and the above test repeated. The average of the two tests is taken as the low frequency efficiency of the coil, which should not be less than 55 per cent.

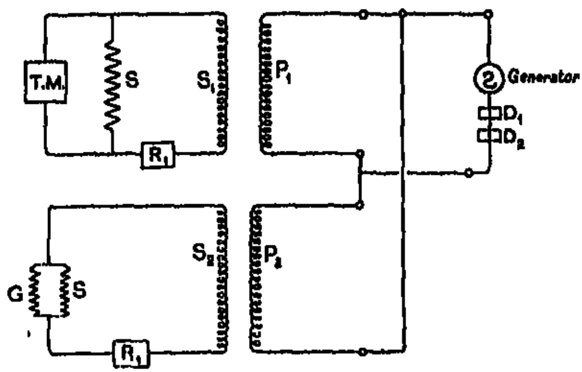


FIG. 104. Diagram of Connections for Efficiency Test.

High Frequency Test.—The shunt on the milliammeter is nc required, and is cut out, also the shunt on G. The power is obtaine from an oscillation generator similar to that shown in Fig. 94, c from a reed-hummer, or from a sounder vibrating No. 2. Th frequency and current need only be approximately correct, a experiment shows that the efficiency at 800 periods per second not appreciably affected by fairly wide variations of frequency an current. Tests in parallel and also in series similar to those at lo frequency are applied. Fig. 105 is a diagram of a testing set whic has proved convenient and provides for changing over—

(*a*) From standard coil to test coil ;
(*b*) From parallel to series ;
(*c*) From low frequency to high frequency.

Repeating coils 4006A are frequently met with which are so accu ately balanced that there is no measurable out of balance of capaci between the windings, and for this reason they are particular suitable for use in the Aldridge test, provided that they are fitt

with the metallic screen between the windings already referred to. The original windings of repeating coils 4006A gave rise to serious cross-talk when the coils were used for phantom working, but the Post Office specified that future supplies should be wound in accordance with the arrangement adopted in drawing No. 7430 (Fig. 106),

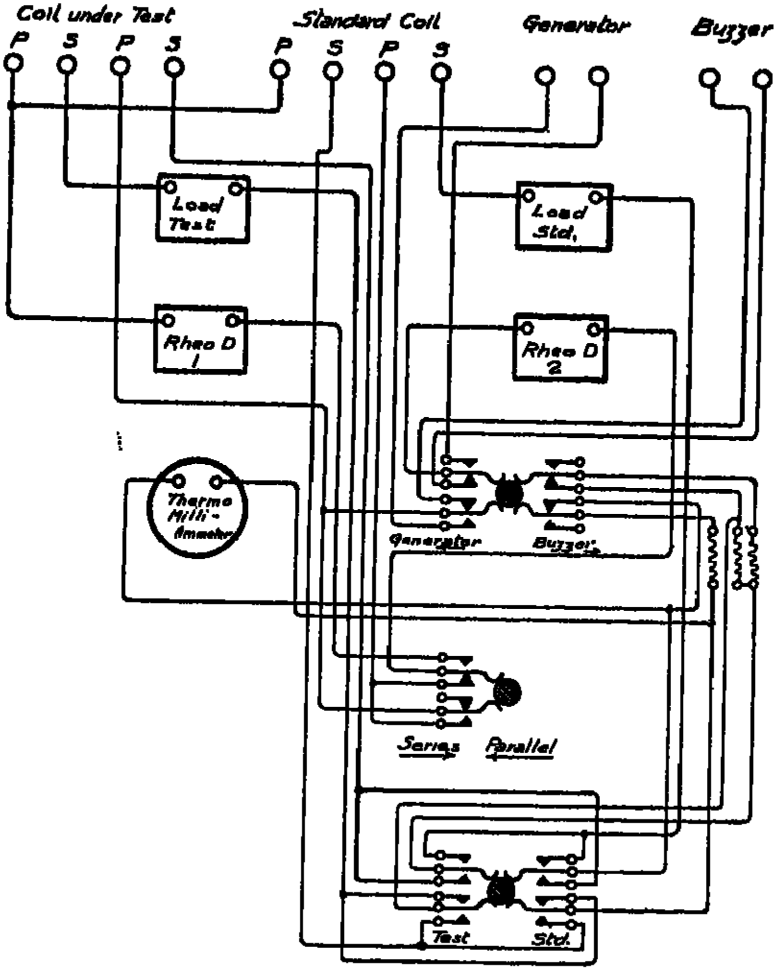


FIG. 105.—Wiring Diagram of Testing Set for Efficiency Tests.

which was first proposed by Mr. S. A. Pollock of the Post Office Engineering Department, for completely balanced windings.

Fig. 106 is a diagram of the winding which is described in the Post Office Specification in the following terms: "The coil to consist of four inductive windings made up of two twisted pairs

wound on a laminated silicon steel core of ring form, as illustrate in Fig. 106. Each of these windings to be wound in two halves joined together during the process of winding as follows: The insid ends of the twinned wires P_1 to be joined to the inside ends of th twinned wires P_2, and the inside ends of the twinned wires S_1 t be joined to the inside ends of the twinned wires S_2. The outsid ends of the same wires, marked with the accented letters P_1', P_2

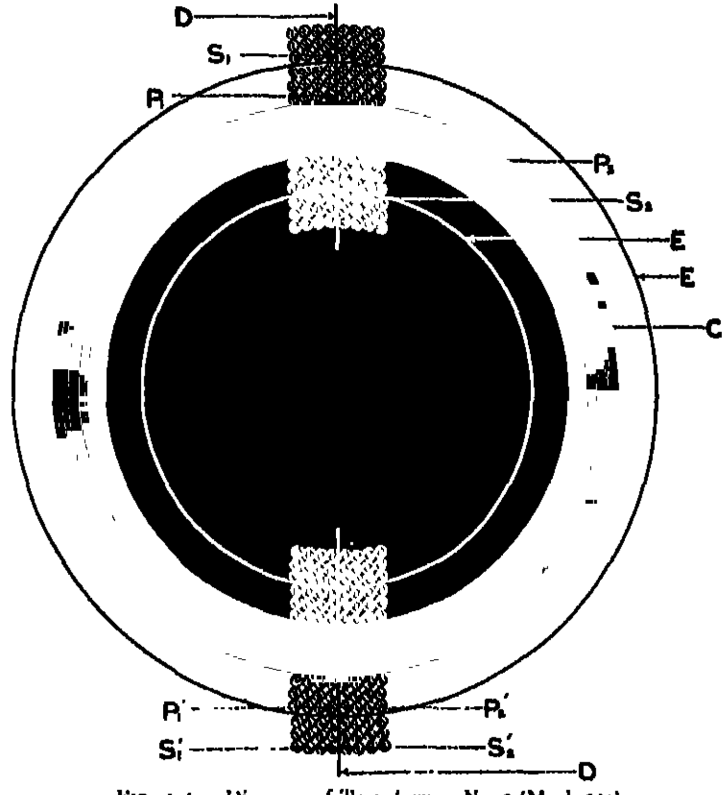


FIG. 106. Diagram of Transformer No. 2 (Mark 234).

S_1', S_2' respectively, to be led out to tags on the base in the ord required to pass test No. 1. The letters DD on the drawing indica partitions between the two halves of the coil to facilitate symmet of construction, and may consist of red fibre impregnated wi paraffin wax. The letters EE indicate a metallic electrostat screen when so ordered, but in the case of this specification th indicate a wrapping of dry cotton tape as a separator between t windings marked S and P respectively."

CHAPTER XVI

THERMIONIC VALVES

THE amplifying valve for telephone purposes has probably not yet reached its final development, and in describing the tests at present made by the Post Office, it should be understood that the tests are tentative and liable to be altered as practical experience may dictate. The valve in most common use by the Post Office at present is of the French type made by the Marconi-Osram Valve Company, and supplies are subjected to the following tests :—

(*a*) Total emission at plate voltage of 150.
(*b*) Power supplied to filament for a total emission of 10 milliamperes and 150 volts in the plate circuit.
(*c*) Grid current at zero potential on the grid and at negative grid potentials.
(*d*) Mutual impedance.
(*e*) Impedance ratio.

FIG. 107.—Diagram for Direct Current Characteristic Test.

In addition, the direct current characteristics are sometimes measured, and speech tests are made on artificial cables to determine the improvement given by the valve when inserted in a telephone repeater set. The latter sets are still being developed and improved so as to suit the various line conditions, and they are not yet standardised finally. It will facilitate the explanation and description of the tests if the direct current characteristic tests are first described. These consist of measuring the plate current—

(*a*) When the plate voltage battery is kept constant and the grid voltage is varied;
(*b*) When the grid voltage is kept constant and the voltage of the plate battery is varied;

the power supplied to the filament being the same in both test The power to be supplied to the filament is determined in the emi sion test, and will be referred to later. Fig. 107 is a diagram

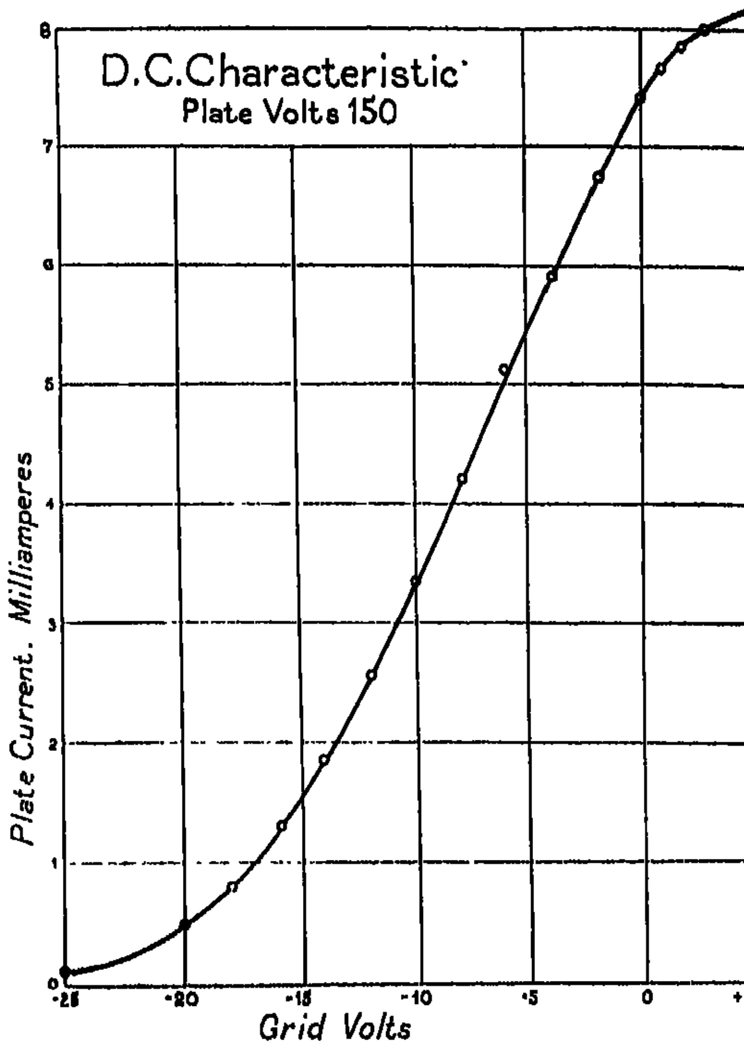


FIG. 108.

the connections for the plate current-grid voltage test, where represents the plate, G the grid, F the filament, B_1 the filamer battery, B_2 the grid battery, and B_3 the plate battery. With B joined direct to the grid, the grid is assumed to be at zero potentia

the potential of the grid being measured with respect to the negative end of the filament. B_2 should have a value of about 30 volts, and it is convenient to arrange for a resistance to divide the potential

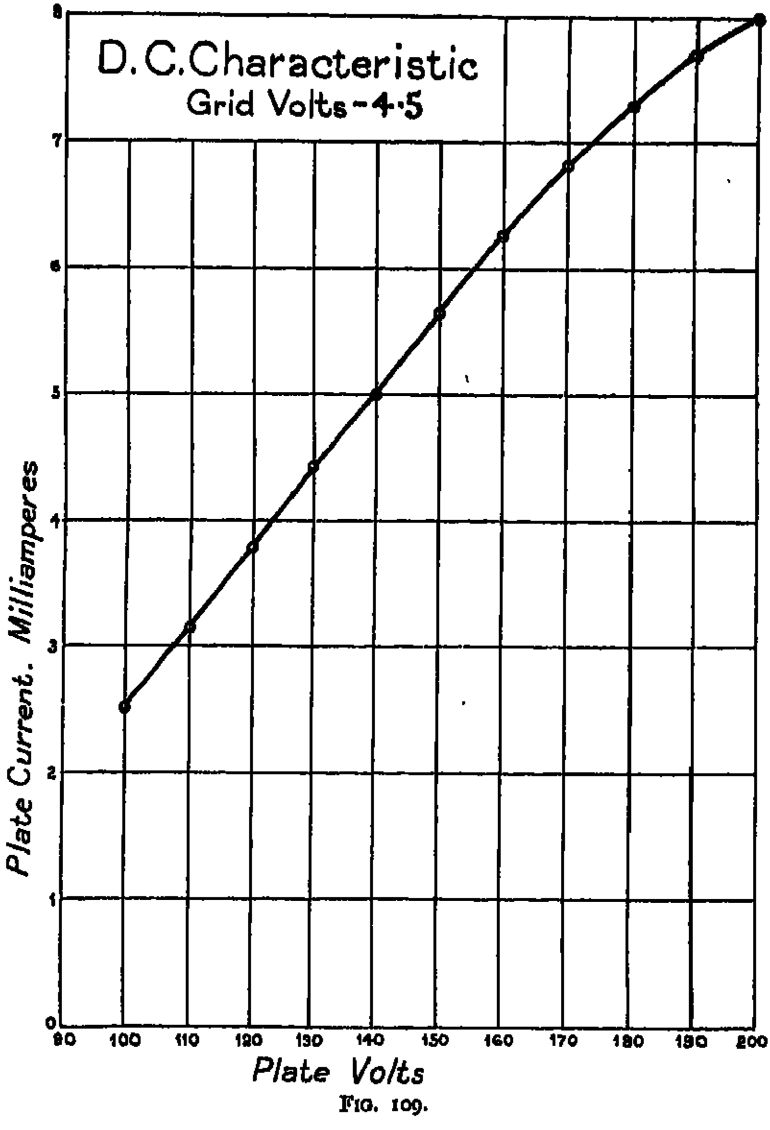


FIG. 109.

as shown in the diagram. B_3 may have a value of 300 volts, variable in steps of 10 or 20 volts. Keeping B_3 constant at some convenient value, say 150 volts, the current in the plate circuit is

read from the milliammeter as the voltage of B_2 is varied in steps of 1 volt from -25 to $+5$. If the plate currents are plotted against the grid volts, curves similar to that shown in Fig. 108 are obtained. It will be seen that between the values of grid volts 0 and -8 the curve is practically a straight line for values of plate volts about 150, and it will be shown later that it suffices in practice to measure the slope of this line at 0, $-4\frac{1}{2}$ and -8 volts, rather than to take the direct current plate current-grid voltage characteristics.

The second direct current characteristic is obtained by keeping the grid battery B_2 constant, and varying B_3 in steps of 10 or 20 volts, whilst the plate current is read from the milliammeter. Fig. 109 shows a curve obtained by this test. It has been pointed out by Dr. Langmuir that the two sets of curves are related, so that for hard valves and for *corresponding values* of the middle parts of the curves the current in the plate circuit is given approximately by the equation

$$I = A(V + Bv)^{\frac{3}{2}},$$

where V is the plate voltage, v the grid voltage, and A and B are constants. If we consider V as constant, the slope of the curve is

$$\left(\frac{dI}{dv}\right)_V = \frac{dI}{d\theta}\left(\frac{d\theta}{dv}\right)_V$$
$$= \tfrac{3}{2}AB\theta^{\frac{1}{2}} = \tfrac{3}{2}AB(V + Bv)^{\frac{1}{2}} \quad . \quad . \quad . \quad (1)$$
$$\text{where } \theta = (V + Bv).$$

Similarly, if we consider v as constant, the slope of the curve is

$$\left(\frac{dI}{dV}\right)_v = \frac{3}{2}A(V + Bv)^{\frac{1}{2}} \quad . \quad . \quad . \quad (2)$$

and if we divide equation (1) by equation (2) we have

$$\frac{\left(\frac{dI}{dv}\right)_V}{\left(\frac{dI}{dV}\right)_v} = B$$

a relationship which is used in some slopemeter tests to be described later.

Total Emission Test.—With 150 volts applied to the plate circuit it is specified that the valve shall give a total emission of 10 milliamperes, and that the filament current shall not exceed 1 ampere. The plate and grid are electrically connected, as shown in Fig. 110.

The filament current is applied and the valve allowed to warm up for a few minutes. The current is then raised until the milliammeter registers 10 milliamperes. The value of the filament

current at this emission read from the ammeter, is noted, and also the potential difference at the terminals of the filament. These values are used in the subsequent tests, and if the valve is approved the values are marked on the base of the valve, and become the values to be used with the valve when brought into practical use.

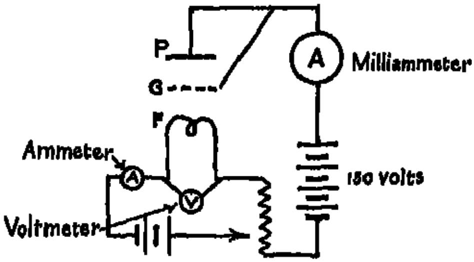


FIG. 110.—Diagram for Total Emission Test.

Slopemeter Tests.—The methods followed in these tests are practically those devised by Dr. E. V. Appleton. Fig. 111 is a theoretical diagram.

It will be seen that by means of the battery B_4 and the adjustable resistance facilities are provided for altering the potential of the grid as desired, since any current i passing through the adjustable resistance R alters the potential of the grid by Ri volts with respect to the negative end of the filament. Before key K is closed the ammeter A registers the plate current I corresponding to zero grid potential. When K is closed an opposing current i flows through the ammeter, and the change in the grid potential is Ri volts. Suppose R is varied until a value is found where no effect is produced on the ammeter when K is opened and closed, and let this value of R be R_1. The increase in the plate current due to the increase of the grid potential by R_1i volts is then exactly neutralised in the ammeter by the current i flowing through R_1. But the increase in the plate current caused by changing the potential of the grid by the amount R_1i volts can be found by multiplying R_1i by the rate of change of plate current with grid potential, that is to say, by $\left(\frac{dI}{dv}\right)_V$ Hence

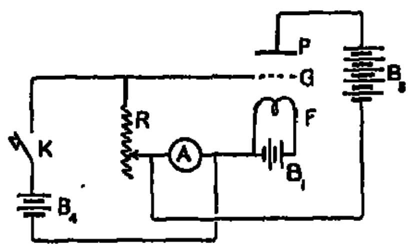


FIG. 111.—Diagram for Appleton Mutual Impedance Test.

$$R_1i\left(\frac{dI}{dv}\right)_V = i,$$

or

$$\left(\frac{dI}{dv}\right)_V = \frac{1}{R_1}.$$

R_1, or its equivalent $\dfrac{1}{\left(\dfrac{dI}{dv}\right)_V}$, is usually called the mutual impedance of the valve. In the method used by the Post Office the battery B_4 is replaced by a buzzer and screened transformer, and the ammeter A is replaced by a repeating coil 4006A and a telephone receiver. Details of the testing set are given later on.

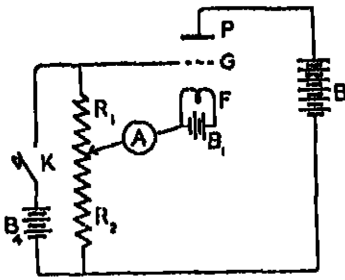


FIG. 112.—Diagram for Appleton Impedance Ratio Test.

Impedance Ratio.—The theoretical diagram is shown in Fig. 112. The ratio of R_1 to R_2 is altered until no change in the deflection of ammeter A is found on opening and closing key K. The effect of applying the battery B_4 is to change the potential of the grid, and also to change the potential of the plate, and when the ratio of R_2 to R_1 is such that no change in deflection is produced on A by working key K, the plate current change due to the change of grid voltage is exactly equal to the plate current change due to the change of plate voltage, and if this current be called i_2 we have

$$R_1 i_2\left(\frac{dI}{dv}\right)_V = R_2 i_2\left(\frac{dI}{dV}\right)_v.$$

$$\therefore \frac{\left(\dfrac{dI}{dv}\right)_V}{\left(\dfrac{dI}{dV}\right)_v} = \frac{R_2}{R_1}.$$

Hence if R_1 is known from the previous test for mutual impedance and the ratio of $\dfrac{R_2}{R_1}$ is found by this test, the value of R_2 is the product of this ratio and R_1, viz.,

$$\frac{R_2}{R_1}R_1 = R_2.$$

R_2 or its equivalent $\dfrac{1}{\left(\dfrac{dI}{dV}\right)_v}$ is usually called the *internal* impedance of the valve, and the method used in the Post Office provides for a buzzer, etc., as in the mutual impedance test. Since we are measuring a ratio in this second test the actual values of the resistances may be any convenient values to suit the testing set, providing the ratio is accurately measured. In practice it is found to be convenient to take smaller resistance values when measuring the

ratio than the value used when measuring the mutual impedance. Let $\frac{R_2}{R_1} = B$, then

$$\frac{\left(\frac{dI}{dv}\right)_V}{\left(\frac{dI}{dV}\right)_v} = \frac{R_2}{R_1} = B$$

or

$$\frac{1}{\left(\frac{dI}{dV}\right)_v} = \frac{B}{\left(\frac{dI}{dv}\right)_V},$$

i.e. Internal Impedance = B × Mutual Impedance.

It will be seen in Fig. 113 that the battery B_2 enables any desired static potential to be applied to the grid while any impedance measurement is being made.

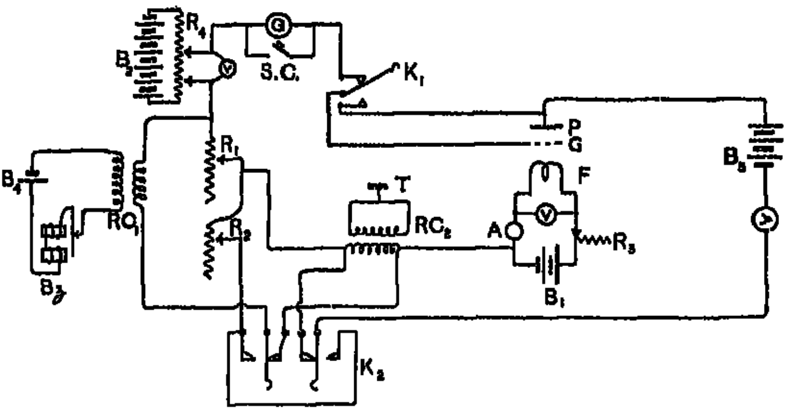


FIG. 113.—Diagram of Wiring of Board used in Appleton Impedance Tests.

Negative Grid-Current Test.—With hard or highly-exhausted valves the grid current is either zero or is so small that it is measured in fractions of a microampere. Some idea, therefore, of the vacuum can be obtained by measuring the grid current at zero grid potential and at some other points, such as − 2 grid volts. To measure the small current it is usual to provide a reflecting galvanometer of the moving coil type.

Fig. 113 is a diagram of a complete testing set which is used by the Post Office, and the following are the details of the apparatus employed :—

B_1. Heating battery, 4 accumulators (capacity, 120 ampere hours).
B_2. Grid battery, dry cells (Y size).
B_3. Plate battery, 100 accumulators, small.
B_4. Buzzer battery, 3 accumulators, small.
RC_1. Screened repeating coil 4006A (W.E. Co.'s make).

RC_2. Repeating coil 4006A (W.E. Co.'s make).
T. Headgear telephone receivers, 60 ohms (Post Office type No. 3A).
R_1. Adjustable rheostat (Post Office type F).
R_2. " " " "
G. Sullivan galvanometer.
S.C. Short-circuit key.
K_1. Key (Post Office No. 85E).
K_2. Key (Post Office No. 28A).
A. Milliammeter 0–15 milliamps (plate current).
Bz. Buzzer (Post Office type Sounder Vibrating).
A. Ammeter 0–1·5 amperes (filament current).
V. Voltmeter 0–15, 0–150 volts.
R_3. Slide resistance, 150 ohms (1·0 ampere).
R_4. " " 1,300 ohms (0·3 ampere).

The voltmeter V across the terminals of the filament can be thrown over to the grid battery resistance R_4 by means of a key, and arrangements on the same key can be made for reversing the grid battery connections to the voltmeter, so that it can be used to indicate not only negative grid potentials, but by throwing the key also positive grid potentials. The latter, however, are seldom measured in routine testing. The repeating coil RC_1 is fitted with an electrostatic screen between the primary and secondary windings, and this screen is connected to a terminal on the case. The terminal is earthed and also a terminal connected to the case itself is earthed. By adopting this earthing device a somewhat sharper balance is obtained and capacity effects are reduced.

Specified Requirements for Valves No. 4.—That the filament heating current shall not exceed 1 ampere, and the maximum voltage drop across the filament shall not exceed 4·7 volts. That the total emission shall be not less than 10 milliamperes at a plate voltage of 150, the plate and grid being connected in parallel. That the mutual impedance at 4½ volts grid potential with a plate voltage of 150 shall be 2750 ± 20 per cent., and the internal impedance 20,000 ± 20 per cent.

Variations in the Mutual Impedance of any one Valve for Variations of Grid Potential.—When the grid potential is varied from 0 to 8 volts the mutual impedance shall not vary more than ± 20 per cent. from the value at − 4½ grid volts.

The amplification factor to be not less than 6·75.

The mutual and internal impedance measurements and the amplification factor to be determined by the slopemeter method. The maximum change of potential to be applied to the grid by the buzzer in a mutual impedance test, to be not more than ± 1 volt on the steady value. With a positive plate potential of 150 volts the current in the grid circuit for negative values of grid potential shall not exceed 0·5 microampere.

Mutual impedance is defined as the reciprocal of the slope of the plate current-grid potential curve at − 4½ volts grid potential.

Internal impedance is defined as the reciprocal of the slope of the plate current-plate voltage curve at $-4\frac{1}{2}$ volts grid potential.

Amplification factor is defined as the ratio:

$$\frac{\text{Internal impedance}}{\text{Mutual impedance.}}$$

The tests are made after adjusting the filament current to give a total emission of 10 milliamperes.

The slopemeter test is intended to prove that the characteristic

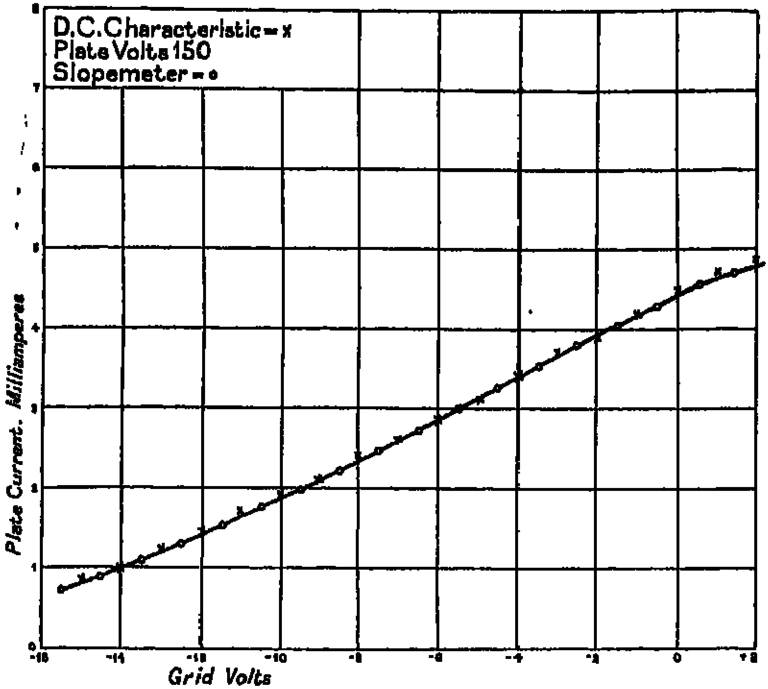


FIG. 114.

curve for mutual impedance does not depart from a straight line to any material extent between the values 0 and -8 volts grid potential, as it is thought that if any part of the knees of the characteristic curve fell within these values, the amplification would be irregular and distortion of speech would result. In order, therefore, that the slope of the curve may be determined over a relatively small part of the curve at 0 and -8 volts, and at any intermediate points desired, it is important that the buzzer shall not change the grid potential by more than ± 1 volt, otherwise deviations from straightness would be masked owing to the slope being taken over too wide a range of potential; in fact, the smaller the potential

change the better, and in practice it is quite easy to arrange for a total change of less than 1 volt. The slope is usually measured at 0, − 4½, and − 8 volts grid potential. If the slope is measured at every 1 volt point from − 30 to + 10 grid volts, and the slopes found are then superposed on a D.C. characteristic curve, there is good agreement between the slopes and the curve practically over the whole range. Fig. 114 is a curve of slopes so obtained with the direct current characteristic points shown by crosses. It will be seen that the lines representing the slopes fall along the points of the direct current characteristic curve.

The foregoing tests apply to English-made valves. In America considerable advances have been made in the development of thermionic valves for telephone use, and also in telephone repeaters. The Western Electric Company are now supplying the Post Office with complete telephone repeater equipment. The valves are not purchased to the specification previously referred to, as they are of an entirely different type, the filament being of platinum-iridium coated with oxides of barium and strontium. As made by the Western Electric Company, these valves require no adjustment for filament current during service, and all valves are interchangeable in this respect. Further, as amplifiers they do not change when the filament voltage is varied between the limits customarily met with in storage battery service. The filament current is 1·3 amps. and the plate volts 130. When tested for mutual impedance the slope of the curve obtained is much steeper than that obtained from English valves, the plate current at zero grid volts being more than double that given by the English valve. The tests described in the foregoing pages for the English valve can be applied with slight modifications to the American valve. The Western Electric Company, however, have designed a special gain measuring set for testing telephone repeaters, and a rough idea of the fundamental principle of the set will be gathered from the following description of the method of testing, which is taken from the Post Office relative instruction.

Repeaters, Telephonic, No. 8A.—Two measurements with a gain measuring set have to be made on each repeater, viz. :—

(*a*) The gain in miles of standard cable produced by inserting the repeater in the middle of a line having an impedance corresponding to the impedance of the line to which the repeater is to be connected.

(*b*) The loss in miles of standard cable between the main circuit and the monitoring circuit.

Diagram R13, sheets 1, 2, and 3, show the circuit arrangements.

As a general statement of the method used, it may be said that a network of resistances is designed so that the current may be made the same through two equal resistances, and when this is effected balance is obtained. To measure the current in the two equal resistances it is necessary to insert a measuring instrument offering exactly the same resistance as one of the equal resistances,

and to provide means for changing over from one position to the other. The following is an explanatory diagram of the network. The resistance values given apply when a repeater for medium loaded lines is under test.

An alternating current is supplied from an oscillation generator G through a transformer T, and passes in series through two adjustable non-reactive resistances A and B. In parallel with resistance A, a resistance D of 1130 ohms is placed. In parallel with resistance B is a network of resistance joined to the input terminals of the repeater under test. This network, together with the input impedance of the repeater, is designed to have a total equivalent resistance of 1130 ohms, and is called the input impedance. The output terminals of the repeater are joined to another network of resistances called the "output" impedance. One branch of this network is a resistance E of 1130 ohms.

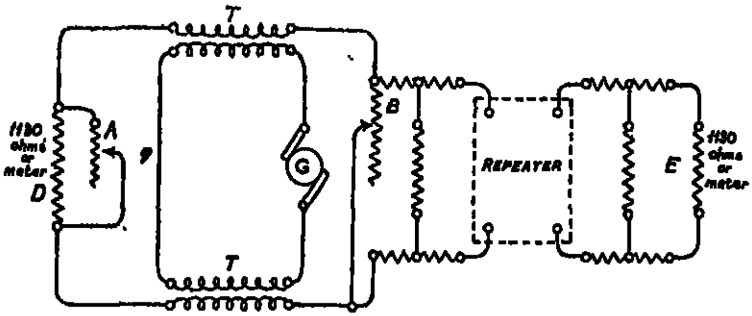


FIG. 115.—Explanatory Diagram of Gain Measuring Set.

By means of the adjustable resistance A the current in D can be varied within limits. Similarly, by means of the adjustable resistance B the current supplied to the input impedance, and hence to the repeater, can be varied within limits. The repeater amplifies the current, and the amplified current passes through E.

The test for gain consists in adjusting A or B, or both, until the currents in D and E are equal.

When this equality is reached balance is said to be obtained. In order to measure the current in D and E it is necessary to provide means for inserting at will a measuring instrument, in place of D or E. This instrument must have a resistance equal to that of D or E, in this case 1130 ohms. When the meter is inserted in place of resistance D the conditions are as shown in the sketch, marked "I. Input" in diagram R13, sheet 2. When the meter is inserted in place of resistance E the conditions are as shown in the sketch marked "II. Output," in diagram R13, sheet 2.

Let the telephone repeater be out of circuit, and let balance be obtained (i.e. the currents in resistance D and E be equal) when the resistance A has a value A_0 and the resistance B has a value B_0.

The improvement in this case is zero, and the position of switches A and B for resistance values A_0 and B_0 will be marked zero. If now a telephone repeater is inserted the current in resistance E will be increased by an amount depending on the amplifying power of the repeater, and balance will be disturbed. Balance may be restored

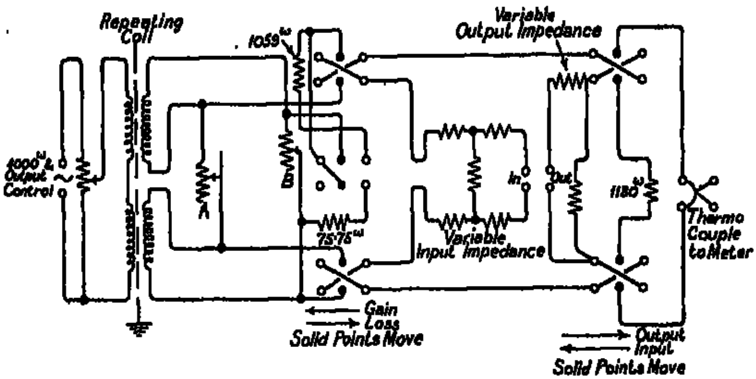
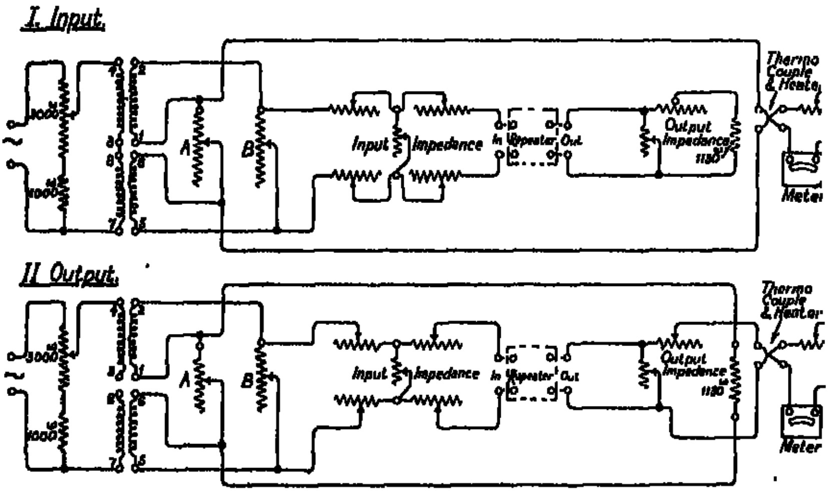


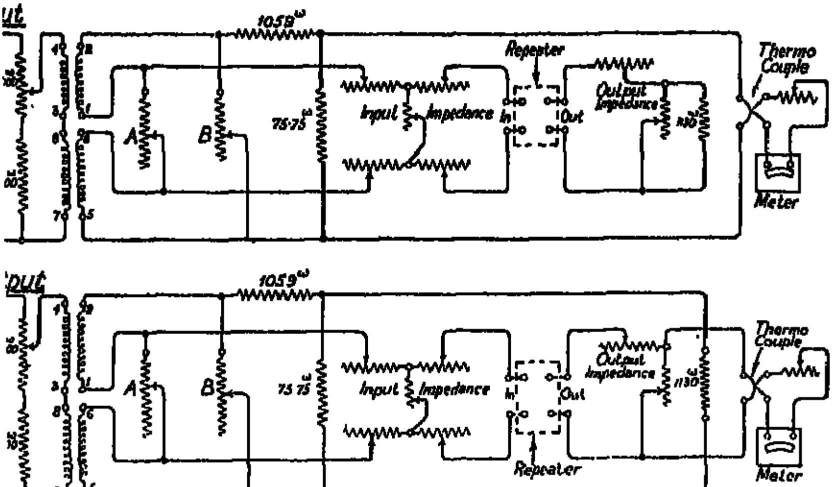
Diagram of Connections for Gain Test. General Switches Neutral.
(*Western Electric Co.'s Diagram, R*13, *Sheet* 1.)



Measurement of Gain.
(*Western Electric Co.'s Diagram, R*13, *Sheet* 2.)

by decreasing the current in resistance E, or by increasing the current in resistance D, or by performing both operations. The current in resistance E may be decreased by decreasing resistance B, and thus reducing the fraction of the main current fed to the repeater. The current in resistance D may be increased by in-

creasing resistance A and thus passing a larger fraction of the main current through resistance D. Thus balance may be restored by moving either switch A or switch B, or both. If the switch B remains at zero the new position of switch A to restore balance will depend on the amplification given by the repeater. It is possible, therefore, to mark switch A in steps, each of which corresponds to an improvement of a definite number of miles of standard cable, thus enabling the improvement given by the repeater to be read directly from the position of the switch. Similarly, it is possible to mark switch B in the same way. Since the fraction of the main current passed to resistance D by resistance A does not depend on the position of switch B, and since the fraction of the main current



Measurement of Loss.
(*Western Electric Co.'s Diagram*, R13, *Sheet* 3.)

fed to the repeater by resistance B does not depend on the position of switch A, it follows that if we move both switches A and B to restore balance, the improvement will be given by the sum of the readings of the two switches. This result also follows from the examination of the equations governing the action of the set given in the appendix which follows.

If it is desired to measure loss with the same set, it is necessary to reverse the function of the resistances A and B, that is to say, resistance A must be placed so as to feed a certain fraction of the main current to the input impedance of the repeater, and resistance B must be placed so as to feed a certain fraction of the main current to resistance D. The connections are shown in diagram R13, sheet 3. In order to enable the same calibration of switches A and B to be used for measuring loss as for measuring gain, it is

necessary to shunt the meter when measuring loss. The 75·75 ohms resistance is inserted for this purpose, the other extra resistance of 1059 ohms being added to bring the equivalent resistance of the whole to 1130 ohms.

The method of operation is exactly similar to that of the test for gain, the *loss* in the apparatus under test being read directly in miles of standard cable on the switches A and B. Arrangements are provided for using a telephone receiver as an indicator instead of a heater and thermo couple, should the current not be sufficient to give a readable deflection on the latter.

When the input and output impedances are not the same, corrections must be made to the dial readings in order to get the true loss. A table showing these corrections is supplied with the set.

APPENDIX

The improvement obtained from a telephone repeater can be expressed by the following equation :—

$$I = I_0 e^{\beta l} \qquad . \quad . \quad . \quad . \quad (1)$$

which is of the same form as the equation for the attenuation of a current in a telephone line, except that the index is positive instead of negative. I is the amplified current and I_0 is the current entering the telephone repeater. β is the amplifying constant and l is a length expressed in miles. If we choose β of a value numerically equal to the attenuation constant of 1 mile of standard cable, then the improvement will be given by l in miles of standard cable.

When the telephone repeater is not in circuit, and the currents in the two equal resistances D and E are equal, the following equation holds :—

$$\frac{A_0}{1130 + A_0} = \frac{B_0 \,.\, K}{1130 + B_0} \qquad . \quad . \quad . \quad (2)$$

where A_0 and B_0 are known values of resistance inserted by the switches A and B. K is a ratio depending upon the values of the resistances composing the network.

If the telephone repeater gives M miles of standard cable improvement, and we are able to balance by moving switch A only from A_0 to A_M, then the following equation holds :—

$$\frac{A_M}{1130 + A_M} = \frac{B_0 \,.\, K \,.\, e^{\beta M}}{1130 + B_0} \qquad . \quad . \quad . \quad (3)$$

Similarly, if switch A is left at A_0 and balance is obtained by moving switch B from B_0 to B_N when another repeater giving N miles of standard cable is inserted, then

$$\frac{A_0}{1130 + A_0} = \frac{B_N \,.\, K \,.\, e^{\beta N}}{1130 + B_N} \qquad . \quad . \quad . \quad (4)$$

Further, if both switches A and B are used to obtain a balance by moving A from A_0 to A_M, and B from B_0 to B_N, and the improvement is, say, P miles of standard cable, then

$$\frac{A_M}{1130 + A_M} = \frac{B_N \cdot K \cdot \epsilon^{\beta P}}{1130 + B_N} \quad \ldots \quad (5)$$

Inserting in this equation from (3) the value of

$$\frac{A_M}{1130 + A_M}$$

we get

$$\frac{B_0 \cdot K \cdot \epsilon^{\beta M}}{1130 + B_0} = \frac{B_N \cdot K \cdot \epsilon^{\beta P}}{1130 + B_N} \quad \ldots \quad (6)$$

We can write equation (4) as follows :—

$$\frac{A_0}{1130 + A_0} \cdot \epsilon^{-\beta N} = \frac{B_N \cdot K}{1130 + B_N} \quad \ldots \quad (7)$$

and we can insert this value of

$$\frac{B_N \cdot K}{1130 + B_N}$$

in equation (6) and obtain

$$\frac{B_0 \cdot K \cdot \epsilon^{\beta M}}{1130 + B_0} = \frac{A_0 \cdot \epsilon^{-\beta N} \cdot \epsilon^{\beta P}}{1130 + A_0} \quad \ldots \quad (8)$$

but from equation (2)

$$\frac{A_0}{1130 + A_0} = \frac{B_0 \cdot K}{1130 + B_0},$$

and consequently equation (8) becomes

$$\epsilon^{\beta M} = \epsilon^{-\beta N} \times \epsilon^{\beta P}$$

or

$$\epsilon^{\beta M} \cdot \epsilon^{\beta N} = \epsilon^{\beta(M+N)} = \epsilon^{\beta P}$$

$$\therefore P = M + N.$$

CHAPTER XVII

TELEGRAPH APPARATUS

GREATER precision of workmanship and a finer degree of adjustment are necessary in telegraph than in telephone apparatus, since the assistance which the human voice supplies in the latter is absent, and the communication has to be made by the movements of the telegraph instrument itself. Especially is this the case in fast speed Morse telegraphy, where a slight turn of the screw of an adjustable contact may increase the attainable speed of signalling twenty or thirty words per minute if made in the right direction. It is important, therefore, to ensure that all adjustable contacts in telegraph instruments provide the necessary facilities for fine adjustment, and that the contacts themselves are in strict alignment, firmly clamped, clean, and finished truly square, so as to provide a good butt contact. In hand-working instruments the speed of signalling is, of course, dependent upon the mood of the operators, and it is fair to say that any improvement in finish or workmanship in the apparatus that tends to the comfort of the operators gives a profitable return, because it increases the speed of signalling. Especially is this the case with Morse keys, and considerable attention is paid to the adjustment of these keys; in fact, as the result of a special investigation by a Post Office committee of experts on the causes of telegraphist's cramp, certain definite requirements have been laid down for the adjustment of these keys and the force required to operate them. These will be referred to more particularly later. The examination of the mechanical details of telegraph apparatus to determine whether the apparatus is suitable for its purpose is always entrusted in the Post Office to very highly trained instrument mechanics, who have a knowledge of telegraph signalling, and perhaps it is not too much to say that the high reputation that the British Post Office Telegraph Department enjoys is in some degree directly attributable to the high grade of workmanship and finish of the instruments used. If the instruments are properly and accurately made their adjustment to the best working conditions becomes a relatively simple matter. The checking of the mechanical details forms an important part of the tests, and those points which receive consistent attention are set forth in the following notes on the several items.

Keys.—Formerly platinum contacts were used on keys, but since 1914, owing to the scarcity of the metal and its high cost, it

has been the practice to fit gold-silver alloy contacts (90 per cent. silver, 10 per cent. gold). Wire contacts are generally of 64 mils diameter, and project $\frac{1}{16}$ inch above the surface of the setting. The depth of setting is also $\frac{1}{16}$ inch, and the contact is soft soldered into a flat-bottomed, plain hole $\frac{1}{16}$ inch deep. Plate contacts are generally $\frac{1}{8}$ inch diameter and 25 mils thick. The insulation resistance between parts which should be electrically separated should be not less than 1 megohm at a pressure of 100 volts. The square holes in the contact springs should fit the squared portions of the pillars without shake, and the springs should be interchangeable with each other and with the spring on the pattern key. The covers of keys should be a good fit and tight enough to allow of the key being safely lifted by means of the cover; $\frac{1}{4}$ inch plate is used for the bevelled glass in the cover. The ebonite bases are not polished. Unpolished ebonite gives better insulation than polished. The whole of the metal work should be free from flaws. The brass work under the base should be tinned. All parts should be interchangeable.

Keys, Double Current.—The contact screws should be capstan headed and should fit rigidly when the clamping screws are tightened. The lacquer should be removed from the underside of the heads of terminal and connection screws. The contact springs are 7 mils in thickness, and are made of well-tempered steel and finely polished. The lever should have a slight side play, and the pressure of the steel contact springs on the ends of the lever axle should not be great enough to prevent the front part of the lever from falling when the antagonistic spring is taken off. The antagonistic spring should be adjusted so that a weight of 6 ounces applied to the knob will just depress the lever. The movement at the front end of the lever should be $\frac{3}{64}$ inch, and the key should operate without undue noise. The ends of the axle and the contact surfaces of the steel springs should be smooth, clean, and free from lacquer. The springs should be adjusted so as to prevent contact between the battery terminals and the line and earth terminals for all positions of the lever. When the switch lever is in the "receive" position the middle terminal at the back should be connected to the right-hand front terminal.

Keys, D.C., 10-Terminal.—The foregoing remarks apply to this key also. The connections of the key are shown in Fig. 116. The key is used on a forked news repeater.

Keys, Reversing 6-Terminal for Quadruplex Circuits and Intermediate Office Universal Battery System, Single Current.—The remarks under "Keys" and "Keys, D.C." apply to this key. The polished steel contact levers, however, are 20 mils thick. The spiral springs should be made of No. 30 S.W.G. (12·4 mils) wire, the convolutions being 105 mils in diameter and $1\frac{1}{8}$ inches long when the spring is closed. When attached to the ivory rocking lever they should have a good working tension when the adjustment screw is in its foremost position. The ivory rocking lever should be perfectly free on its central bearing, and when at rest should

stand at right angles to the key lever. The battery should be momentarily short-circuited when the key is operated. Lamp resistances are fitted in the battery circuit. The two front terminals should be capped with ebonite. The contact levers should be perfectly free on the spindle and without shake. The contact discs on end plates should be 25 mils thick and $\frac{5}{16}$ inch diameter.

Keys, Single Current 3-Terminal for Single Current Working and C.B. Telegraph Circuits.—The lever axle should be well fitted in the lever with slight side-play in the saddle-fitting, in which it should work freely. The contacts should be in alignment. The antagonistic spring of the lever should be capable of such adjustment that the lever will be depressed by any weight between 2 ounces and 4 ounces placed upon the knob of the key, the usual tension of the spring being such that 4 ounces placed on the knob will just depress the lever. The parts should be interchangeable with the pattern. The back contact screw and its clamping screw should be capstan headed, the latter being of steel tempered to a blue colour. The knob should be of polished horn and tapped only so far as the screw

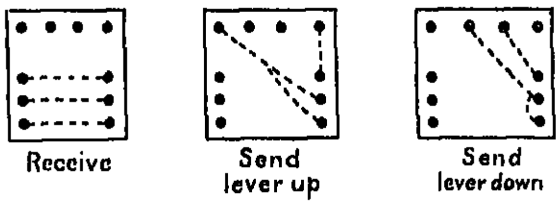


FIG. 116.—Connections of D.C. Key 10-Terminal.

enters. The brass parts should be polished and coated with pale gold lacquer, except on the contact surfaces of terminals, etc. The heads of the screws fixing the blocks to the base should lie flush with the surface.

Keys, Single Current 4-Terminal and 2-Front Contacts.—Used at central stations on C.B. telegraph circuits. The notes appearing under "Keys S.C." apply to these keys. The front adjustable contact should be adjusted to make before the front fixed contact is made when the key is depressed. A hexagonal lock-nut, recessed to allow the capstan head sufficient play for adjusting purposes, should be fitted to the front adjustable contact. The contact disc on the contact spring should be $\frac{3}{16}$ inch diameter and riveted to the spring. The spring should be $6\frac{1}{2}$ mils thick and nickelled. The spiral spring should be of hard-drawn nickel silver wire, No. 22 S.W.G., and consist of twenty-two convolutions.

Key, S.C., with Switch 4-Terminal.—Reversing key for universal (split) battery working, and *key S.C., with switch, 6 terminal,* for C.B. telegraph working. The notes appearing under "Keys, S.C.," apply to these keys. The spring lever should make good contact with the two switch blocks. The switch lever should have a firm

and decisive action, and there should be a slot $\frac{1}{8}$ inch by $\frac{5}{16}$ inch in the ebonite base between the switch blocks. The 4-terminal key is usually provided with a hooked brass strip, clamped beneath the washer of the front left-hand terminal to lock the switch and prevent its being inadvertently knocked over when continuous attention is not given to the circuit. The key lever should be a good fit in its bearings and without any appreciable side-shake. The tapered pin upon which the lever works should be of steel, and should fit without shake. The iron and steel screws should be blued and lacquered. The brasswork above the base (except the switch contacts, which are tinned) should be polished and coated with pale gold lacquer. Contact surfaces should be free from lacquer. The brasswork beneath the base should be tinned. The bridge-piece of the switch should consist of a brass core covered with ebonite, cured-on and engraved " Send " and " Receive." The ebonite base should be left plain and not polished.

Keys Nos. 6 and 6A.—Plug keys for use on concentrator lamp-signalling switchboards. The side-play of the plugs in the sockets should be just sufficient to allow of free action of the plug. With the plug depressed, the short spring should engage behind the ball of the plunger so that sufficient locking is ensured. The inner and outer contact springs should have ample clearance when the plug is depressed. With the plug withdrawn to the maximum limit, the contacts should be in alignment and make good contact. The stem of the plug should be fitted with a brass ring and a pin, which normally slides in a groove in the socket so that the plug, when pulled out and turned round through 90°, will be locked in the extended position.

Indicator Keys, E.M. (Electromagnetic), Resistance 25 + 25 *ohms.*—The indicator disc should be of aluminium painted in twelve segments, alternately black and white. The white should be slightly smaller than the black segments. The spindle carrying the disc should be squared into the boss of the disc and pinned. The disc should be free to rock, and should be fitted and adjusted so that the white star will be entirely hidden when the plunger is normal, and will be fully exposed when the plunger is depressed. Both the contact and the ivory-tipped screws should be firmly held by their respective clamps, the screws for which should be capstan headed. The armature should be pinned to the axle by a steel pin, and when operated should be equidistant from the cores. The contact tongue should be in alignment with both the contact and the limiting screws. The coils should be firmly held by the fixing screws. The pivots of the armature axle should be well polished, and the bottom pivot should have a well-rounded and polished end. The armature spring adjusting pillar should be friction-tight and allow sufficient range for the adjustment of the spring. The plunger should return smartly after being operated. The contact pillar should be insulated by means of an ebonite washer.

The indicating shutter should be securely riveted to the armature

axle, and the shield recessed to engage with a steady pin fitted in the brass top plate. The wire ring holding the shield should be securely fitted. The indicator should be capable of adjustment so that the armature will remain attracted and the white star exposed when a current of 6 milliamperes is passed through the coils.

Key 87B.—Used for concentrating telegraphs, C.B. and D.C. circuits. This is of telephone-key type, having six nickel silver switch springs on each side of an ebonite plunger. The contacts—gold-silver—should be in alignment. The ebonite plunger should be screwed on tightly to the threaded portion of the lever, and its end should be squared to facilitate removal. The knob is screwed to the lever. The lever should lock on either side, and when operated should make two contacts and disconnect two. In the middle position of the knob two contacts are made on each side.

Galvanometers Differential, Vertical.—Used in duplex and other telegraph circuits. The resistance of each coil is 50 ohms shunted with 300 ohms, that is, each coil has a resistance of approximately 42·9 ohms; 43 ohms is engraved between the terminals of each coil. The coils are wound with 10 mils, silk-covered, copper wire, and the shunts with 3 mils, silk-covered, copper wire. The coil end spirals are of 16 mils, double silk-covered wire. The wires for the differential coils are sometimes twisted together before winding, in which case 9 mils wire is allowed.

The needle, when facing north or south, should be quite vertical when at rest. When placed in this position it should show an equal deflection on either side of zero of not less than 40°, and not more than 50° when a current of $17\frac{1}{2}$ milliamperes is sent through each coil separately. The front pointer is weighted at its lower end, and thus provides means for adjusting the sensitivity. With the coils joined in opposition (1) series, (2) parallel, and the case inclined so that the pointer stands at any point up to 30°, the needle should remain perfectly steady when a current of 100 milliamperes is sent through each coil, i.e. a total current of 200 milliamperes should be used when the coils are in parallel.

The soft iron fork should be securely soldered to the axle, and should not foul the bobbins when the needle is fully deflected in either direction. The needle and axle should be freely balanced in the pivot-holes with slight end-shake. The dial bridge should be steady pinned. Two brass limiting pins should be fitted at the ends of the engraved scale. The nickel silver cross connection springs should be of hard rolled metal, and have a distinct set so as to ensure good contact. All the brass work should be of the best hard-rolled or hard-drawn metal, except the outer coil cheeks, front bridge, glass bezel, and cross-piece, which may be of best yellow cast brass. The pieces of soft iron to which the permanent magnets are attached should be dovetailed and hard-soldered into the coil cheeks. The permanent magnets should be of the best tungsten steel. The circular brass dial should be covered with a paper dial printed from a copper plate—the plate is usually supplied

to the contractor—on best Bristol board, sized and varnished so as to leave it a pale cream colour. The Bristol board should be approximately 7 mils thick and stuck on evenly to the brass plate with a reliable adhesive.

Single Current Galvanometer.—Resistance, 15 + 15 ohms. The coils should be wound with silk-covered copper wire 14 mils thick, and the shunt with silk-covered platinoid wire 4 mils thick to a resistance of 1000 ohms. The shunt bobbin should be of ebonite of B quality. (See chapter on "India-rubber" for B quality.)

The resistance should be within $\pm$ 1 per cent. The needle when at rest and facing either north or south should be vertical, and should deflect to the stop pins on either side with a current of 9·3 milliamperes.

The distance from the centre of the dial to that of each stop-pin should be $\frac{3}{4}$ inch, and from centre to centre of the two stop-pins, $\frac{1}{4}$ inch. The stop-pins should be $\frac{3}{32}$ inch in diameter. The details under differential galvanometers as regards the permanent magnets, soft iron pieces, and Bristol board apply to this galvanometer.

Galvanometer, Horizontal Complete in Leather Case, 800 *ohms.*—The coils should be wound with silk-covered wire 5 mils in diameter to a resistance of 800 ohms at 60° F. The resistance should be within $\pm$ 1 per cent. With a current of 0·048 milliamperes the needle should deflect not less than 25°. The needle should be of best tungsten steel, properly hardened and thoroughly magnetised. It should be carefully pivoted so that it will oscillate not less than ten times in coming to rest after a full deflection. The magnet of the needle should be fitted so that the north pole is to the right when the coil is between the observer, and the scale and the connections of the coil should be such that the pointer will then be deflected to the right when the positive and negative leads of a testing battery are connected to the right- and left-hand terminals respectively. The needle lifting piece should be perfectly free, and when operated should lift the magnet and needle off the needle-point.

Galvanometer, Horizontal Uni-pivot.—Resistance, 50 ohms (approximately). The needle should deflect not less than 10° when a current of 16 microamperes is applied to the coils, i.e. a pressure of 1 volt through an external resistance of 62,500 ohms. The surfaces of the pole ends should be smooth. The safety lift-piece should work easily and be free of the bottom of the moving coil when not in use. The moving coil should be free in all positions and clear of the magnet poles. The lower coil connection should be just long enough to allow the coil to turn to its maximum extent. The aluminium pointer should be firmly secured to the removable coil movement. The contact springs on the brass cover should make reliable connection with the contact plates when the cover is screwed into position. The galvanometer, when placed on a flat surface, should release the coil by means of the safety lift-piece fastened to the brass base. Lifting the instrument should raise the coil from its pivot automatically. To adjust the pointer to zero,

the screw clamping the torsion head should be slackened and the latter turned by means of its lever.

To Remove the Coil.—The coil movement, the front half of the core, and the lower jewel screw should be removed and the end of the spring unpinned. The coil may then be lifted out.

Rheostats.—For telegraph purposes rheostats are not required to be of a very high degree of accuracy, and it is usual to specify that they shall be within 1 per cent. either way of the indicated value at 60° F. The resistance of each coil of the rheostat should be checked against the corresponding coil of a standard rheostat. This can be readily done by inserting the standard rheostat in the section of a Wheatstone bridge, as shown in Fig. 117, the rheostat under test being connected in the ordinary way. If balance is not obtained the third arm of the bridge can be used to ascertain the extent of the unbalance. The coils should be non-inductive, i.e. double-wound. The plugs should be interchangeable with each

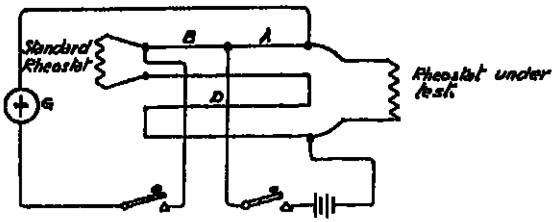


FIG. 117.

other and with the pattern plug. The plugs should fit accurately into all the holes without shake, and the plug end which is required to make contact should be free from lacquer. The plug-holes should be well polished and not lacquered. There are four different patterns of rheostat, viz., "C," "D," "E," and "F" in use in the Post Office service.

Rheostat C.—The range of resistance is from 10 ohms to 8430 ohms in steps of 10 ohms. The bobbins should be double-wound with silk-covered platinoid wire, the details of the coils being as follows :—

Coils No. 1.	Five coils, each 400 ohms, 8½ mils wire		Single silk covered.
,, 2.	Three ,, ,, 9 ,,		
,, 3.	Two ,, ,, 6½ ,,		
and	One coil 4000 ,, 4½ ,,		
,, Nos. 4 and 5.	Five coils each. Each coil 40 ohms, 12 mils wire		Double silk covered.
,, No. 6.	One coil, 10 ohms, and one coil 20 ohms, 22 mils wire		

Bobbins Nos. 1 and 2 should be of brass and the remainder of ebonite. The two revolving contact arms should fit accurately and

without shake in their bearings, and move freely and independently. The contact springs on the arms should be hardened and tempered. All the platinoid studs should be of the same height, and their hemispherical stops should be burnished so that the locking of the platinoid sliding contact may be equal upon each. The platinoid contacts should be solid blocks, well hammered to render it as hard and durable as possible. The switch blocks should be well hammered castings free from all flaws and defects.

Rheostat D has the same range of resistance as rheostat C, but the contact arms are of a different shape and move over two independent circles of contact blocks. Each contact arm is made up of three springs of hard-rolled phosphor bronze, 25 mils thick, and two shorter spacing pieces. The turned down ends should bear evenly and truly on the contact studs. The springs should have an appreciable downward set. The contact studs should be of hard-drawn brass, with their chămfer-edged tops perfectly level and of uniform height, so that the contact springs may bear equally upon each. The brass connection wires should be soldered. There should be no disconnection of the circuit when the arms are rotated. The top is of $\frac{1}{2}$ inch ebonite, smooth finished, but not polished, and fastened to the woodwork by countersunk brass screws. Fixing lugs should be countersunk for No. 6 wood screws, and the edges of the inner surface should be slightly rounded so as to avoid injury to instrument tables. The engraving of the letters and figures should be $\frac{1}{8}$ inch in height and white-filled. The main bobbins are of brass, fitted with thin ebonite sheaths and ebonite separating discs between the coil sections. The sections are wound on a former corresponding with that of the bobbin and set in paraffin wax. When the proper sections have been placed over the core of a bobbin, the lower movable cheek is screwed down and the whole again dipped in melted wax. There are ten sections each 40 ohms of 13 mils double silk-covered wire on one bobbin, and ten sections of 400 ohms each of single silk-covered wire, on a second bobbin, three sections being wound with 9 mils wire, and the remaining seven with 6·5 mils wire. The larger wire sections should be connected to the first three studs, viz., 400, 800, and 1200 ohms. A third bobbin is wound to 4000 ohms with 5 mils single silk-covered wire, and a fourth bobbin in two sections separated by a brass disc, is wound with 24 mils wire double silk-covered to 20 ohms and 10 ohms respectively. All coils are double-wound and of platinoid wire. The plug switch-blocks should be steady pinned in position. The ebonite knobs should be steady pinned to the brass stems. The head of the knob should be milled.

Rheostat E.—This rheostat is also described as the Metropolitan rheostat. It has a range of resistance of 1175 ohms in steps of 25 ohms. A blued steel pointer is screwed to the brass side of the case, and the head of the case consists of a silvered dial, on which the resistance values are engraved, which can be rotated, bringing the different resistance values opposite to the fixed pointer. The contact studs are of platinoid, and should project equally above the

ebonite disc so that their hemispherical polished ends shall lock into the contact spring satisfactorily. The circular spring should be faced with platinoid at the contact position. The bobbins should be double-wound with 8½ mils silk-covered platinoid wire. The dial should be covered with a glass plate ⅛ inch thick.

Rheostat F.—This is similar to rheostat D, but four additional plug resistances, viz., 1 ohm, 2 ohms, 3 ohms, and 4 ohms are provided.

Leak Coils, 40,000 ohms.—Each of the eight coils should be evenly double-wound with silk-covered platinoid wire 4½ mils to a resistance of 5000 ohms. The six plugs should be interchangeable with each other and with the pattern and the plugholes should be polished and not lacquered. The whole of the brasswork including the plugs and terminals should be of best hard-drawn or hard-rolled metal.

Telegraph Relay, Standard B.—In order to secure accurately made relays it is the practice to supply contractors (1) with a pattern relay, (2) with a set of parts, and (3) with a set of gauges and templates comprising the following :—

Gauge for hinged tongue.
" " wood base.
" " brass arbor.
" " armature.
" " iron cores.
" " coils bobbins.
" " steel end plates.
" " ebonite stops.
" " pillar and lever.
" " brass cover.
" " permanent magnet.
" " top plate.
" " bottom plate.
" " adjusting block and screw.
" " terminal plates.
" " thread of contact screws.
" " connection links.
Templates for drilling wood bases.
" " " bridges.

The principal stipulations of the specification are as follows :—

All parts should be made accurately to gauge and template, and should be interchangeable. All the brass work should be of the best hard-rolled or hard-drawn metal. The concentric ring carrying the local contacts should be made of dense well-hammered gun metal. The local contact arm should be fitted with a hinged tongue of nickel silver, dovetailed and soldered into the cross platinum contact. The tongue should fit accurately, and friction tight when the capstan clamping screw is free. The two armatures, and the cores of the electro-magnets should be of the best Swedish or other approved iron. The cores should be turned from a solid bar. The iron should

be annealed so that the finished relays will not retain a perceptible trace of residual magnetism after a current due to an electromotive force of 50 volts has been sent through the coils on short circuit. The iron should not be tooled or filed after the annealing process. The permanent magnets should be of best tungsten steel, and be fitted with the north-seeking pole downwards. The two brass screws carrying the platinum contacts are made with a special thread —to gauge— and must be similar to and interchangeable with the pattern. The screwed adjustment regulating the position of the tongue and armatures should be constructed so as to permit of the brass pin riveted into the upper armature touching the core ends of the electro-magnets when it is at either limit of its range, the screws being adjusted so that the tongue shall have 5 mils play between the contacts. The spiral connection between the base and the arbor should be of uncovered soft copper 4 mils wire. Each of the coil bobbins should be double-wound in two sections with single silk-covered (natural colour) copper $5\frac{1}{2}$ mils wire. The double wire should be threaded through a small hole in the ebonite cheek between the two sections, the ends fastened down and the first section filled; the ends which have been threaded through should then be jointed to another length of double wire, and the second section should be filled by spinning the bobbin in the reverse direction. Each of the wires on each complete bobbin should be of 200 ohms resistance, making a possible total of 800 ohms for the two bobbins. The similar windings of each bobbin should be joined in parallel between the connection plates giving a resistance of 100 ohms between terminals D and U and 100 ohms between terminals (D) and (U). The resistances should be within $\pm$ 1 per cent. at 60° F. Each pair of wires should be led out from the bobbin by means of ends of double silk-covered copper wire 16 mils in diameter and coloured green and white respectively. Each winding on the same bobbin should consist of an equal number of effective turns so that the completed relays will be perfectly differential. When terminals U and (U) are connected together and a current of 250 milliamperes is sent through the coils from terminal D to terminal (D) the armatures must be entirely unaffected. When a relay is properly adjusted it should give reliable key-speed signals with a current of 0·5 milliamperes. The relay should be capable of repeating good Morse signals at a speed of 400 words per minute with a current of $17\frac{1}{2}$ milliamperes, the coils being joined in parallel. For this test an external resistance of 3200 ohms is connected in series with the relay, a condenser of 2 mfd. capacity being joined across 1600 ohms of the external resistance. The brass links connecting terminals D and (D) and U and (U) should not be lacquered. The hinged covers of the relays should be a perfect fit and interchangeable. They should pass freely over the top plates and be a true fit upon the bottom plates. The tops or lids should be friction tight upon their hinges so that they will remain firmly in any position

to which they may be lifted. The wood base should be made of the best seasoned Spanish mahogany, well polished externally and treated with polish on the internal surface. The metal work under the base should not project beyond the base level when the terminals are screwed home.

Figure of Merit Tests.—A special board to facilitate the testing of fast speed telegraph apparatus is desirable and the diagram of connections of such a board is shown in Fig. 118. For adjusting the figure of merit currents two rheostats F and a detector No. 2 are provided. Switch No. 1 provides facilities for changing over from the small battery to the large battery; switch No. 2 is a battery reversing switch, and switch No. 3 changes over from single current to double current. Switch No. 4 provides (*a*) for short circuiting the differential galvanometer, (*b*) for using one coil of the galvanometer, (*c*) for using the full galvanometer. No. 5 is a 7-hole U link test pillar, and provides facilities for altering the connections from series to parallel either normal or differential as shown by the diagrams at the side of No. 5. With a U link in the top left-hand pair of holes, and another U link in the middle and lowest holes the set is arranged for testing a relay standard B at slow or key speed, i.e. the relay is joined in normal series. The current is adjusted to half a milliampere switch No. 1 being to the left (small battery 2-50 volts), and the key is worked operating the sounder connected to the Wheatstone receiver. Good reliable signals should be received. With a U link in the left-hand bottom pair of holes, another in the middle and top holes and a third U link in the right-hand pair of holes, the relay is connected in normal parallel for fast speed working. The relay is tried at 400 words per minute No. 1 switch being turned to the right (large battery, 60 volts), and the current adjusted by means of the rheostat F and the detector No. 2 to $17\frac{1}{2}$ milliamperes. The Wheatstone transmitter is timed with a measured piece of slip to the exact speed of 400 w.p.m. and the transmitter is then run continuously, the relay under test repeating the signals to the Wheatstone receiver. It will be noticed from the diagram that in the local circuit of the relay are inserted a resistance of 1600 ohms + 1600 ohms shunted with a 2 mfd. condenser, in series with a differential galvanometer, Wheatstone receiver, and split 65 volt battery, the total resistance in the local circuit being approximately 3500 ohms.

Differential Series Test.—U links are inserted in the test pillar No. 5 connecting the bottom and left-hand holes and the middle and top right-hand holes. The relay should be unaffected, that is the tongue should remain stationary, when a current of 250 milliamperes is passed through the relay. It will be seen from the diagram that with the links in the positions stated above terminals U and U are connected and the current flows through the relay from terminal D to D.

Differential Parallel Test.—U links are inserted in the top and top left-hand holes, the middle and lower left-hand holes and the

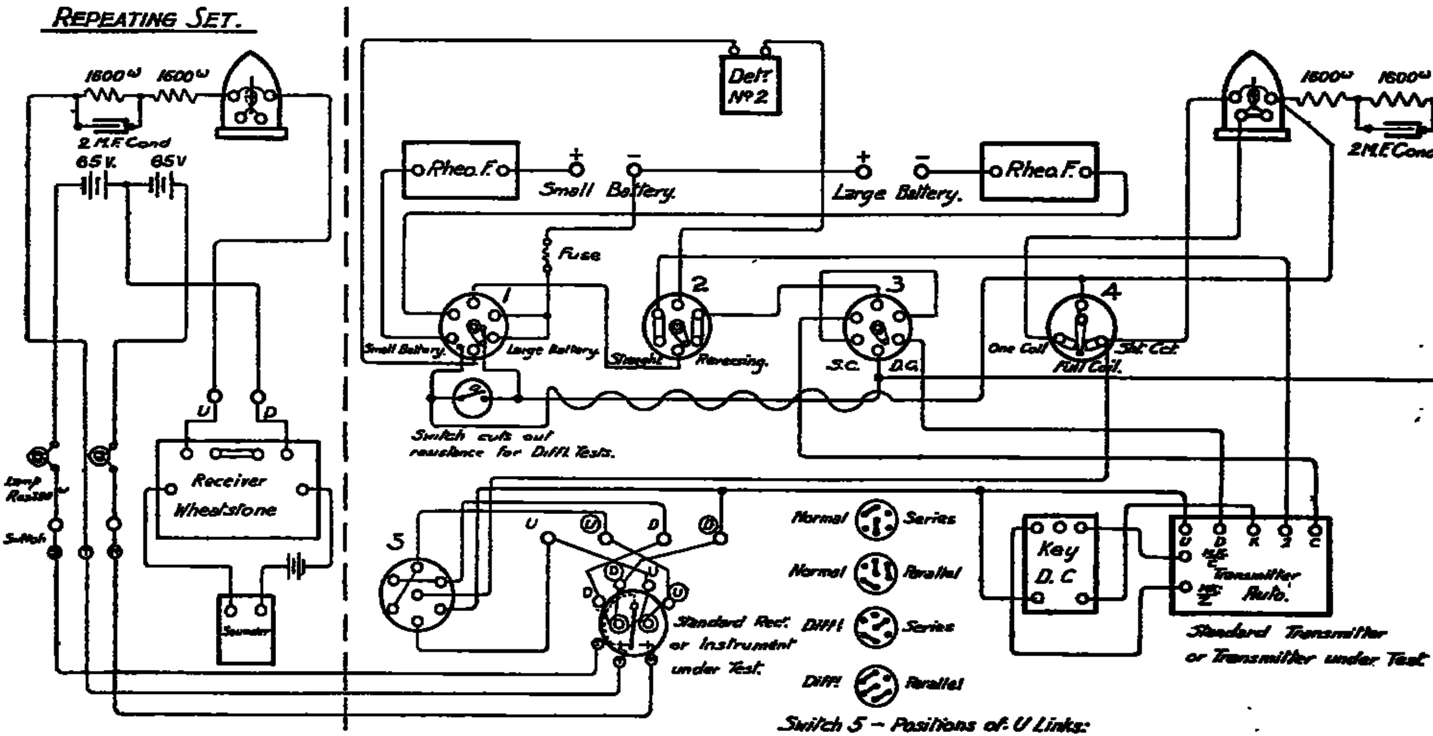


FIG. 118.—Wiring Diagram of Board used in Testing Fast Speed Apparatus.

bottom and lower right-hand holes thus connecting terminals (U) and D and terminals U and (D) together. The relay should be unaffected, that is the tongue should remain stationary when a current of 200 milliamperes is passed through the relay.

Polarisation Test.—A current of 250 milliamperes should be applied in the spacing direction for 15 seconds, and the tests previously mentioned, viz., 400 w.p.m. with $17\frac{1}{2}$ milliamperes and key speed with $\frac{1}{2}$ milliampere should be repeated.

Adjustment of Relay Standard B.—In the event of the relay not repeating satisfactorily at 400 words per minute it is desirable to overhaul the adjustment, and the following procedure has been found to give good results:—

(1) The permanent magnets should be adjusted with relation to the soft iron armatures so as to ensure that the spindle and armatures will when lifted fall into position by their own weight, the pivots fitting without shake but being quite free. N-pole of magnet downwards and approximately $\frac{1}{16}$ inch from armature tongue.

(2) The tongue should be in a central position with regard to the contacts. To effect this open out the large adjusting screw to the limit of its range, then screw the adjusting screw inwards, counting the turns in $\frac{1}{4}$ turns and thus ascertain the total range of movement. Open out the adjusting screw to its middle position, i.e. half the total number of turns of its range.

(3) Adjust contacts with respect to tongue by advancing the spacing contact until the tongue just moves off as though of its own accord, then withdraw the spacing contact until the tongue will just stay on it. When this has been attained the marking contact should be closed up until the desired degree of closeness is obtained. The contacts should not be too close or there is danger of momentary short circuits. If there are lamp resistances in the battery leads, they can be used to obtain the final adjustment since, by advancing the marking contact until it reaches the tongue, the lamps will glow; then immediately withdraw the contact sufficiently far to put out the lamp. The tongue can be worked with the finger to ascertain whether any short circuit occurs as the armature moves.

The resistance of the coils is measured either by Wheatsone bridge or by combination testing set, and the insulation resistance taken between the windings should be not less than one megohm at a pressure of 100 volts. The speed of the transmitter in words per minute is usually determined by timing 10 feet of slip in passing through the transmitter at the particular speed desired. Ten feet is taken as representing 50 average words, so that at 400 words per minute 10 feet of slip would take $7\frac{1}{2}$ seconds to pass through the transmitter. A stop watch is used for timing the slip.

Relay Standard B, Neutral, 100 + 100 *ohms.*—This is similar to relay standard B except that it is fitted with neutral adjusting springs. The neutral adjusting springs are taken off while the tests are being made, and consequently the testing of this relay does not

differ from the ordinary instrument. For Baudol sets a relay standard B fitted with a rectangular base 4¾″ × 3¾″ is provided, but it differs in no other respects from the ordinary instrument.

Relay Standard A, 200 + 200 *ohms.*—This relay is tested at key speed. It should operate reliably with ½ milliampere with the coils connected in series, and be differential with 100 milliamperes in series and 200 milliamperes in parallel. It is not used for fast speed signalling in the present day as it is superseded by relay standard B. The principal differences between the two relays are in (1) the windings; relay standard B having twice the number of turns and half the resistance of relay standard A, and (2) the tongue; relay standard A is not fitted with a hinged tongue providing facilities for cleaning the tongue contacts.

Relay Standard G.—This relay is a converted relay standard B, the conversion consisting of providing auxiliary coils and terminals so that the relay may be made to vibrate on the same principle as the Gulstad relay. The following are the details of the windings.

Line Coils.—Each of the coil bobbins is double wound in two sections with single silk-covered enamelled copper wire 5½ mils in diameter to a resistance of 200 + 200 ohms. The double wire is threaded through a small hole in the ebonite cheek between the two sections, the ends fastened down and the first section is wound; the ends which have been threaded through are then jointed to another length of double wire, and the second section is wound by spinning the bobbin in the reverse direction.

Auxiliary Coils.—Each of the coil bobbins is then double wound in a similar manner to the line coils with single silk-covered enamelled copper wire 3 mils in diameter to a resistance of 200 + 200 ohms.

Each of the wires on each complete bobbin is of 200 ohms resistance making a possible total of 800 ohms for the two bobbins of each coil, i.e. line coils and auxiliary coils. The similar windings of each bobbin (of the line coils) are joined in parallel between the connection plates giving a finished resistance of 100 ohms between terminals D and U and 100 ohms between terminals (D) and (U). The windings of the auxiliary coils are connected to the three terminals marked A, B, and C as indicated on Fig. 119. The resistances should be within ± 1 per cent. of the stated values. Each pair of wires of each coil should be led out from the bobbin by means of ends of double silk-covered copper wire 16 mils in diameter and coloured green and white and red and blue respectively. To avoid contact between the coils and the frame, the ends of the coils should be brought out directly above the corresponding hole in the base and carried down by the side of the coils through an insulating sleeve. Each winding of the line coils on the same bobbin should comprise an equal number of effective turns in order that the complete relay may be perfectly differential. When terminals U and (U) are connected together and a current of 250 milliamperes is sent

through the coils from terminal D to terminal (D) the armature should be entirely unaffected.

Figure of Merit.—Line coils: Key speed $\frac{1}{2}$ milliampere auxiliary coil circuit open. Fast speed at 400 words per minute, $7\frac{1}{2}$ milliamperes. The usual arrangement for the fast speed test is 120 volts, 4000 ohms external resistance and a reading condenser of 0·5 micro-

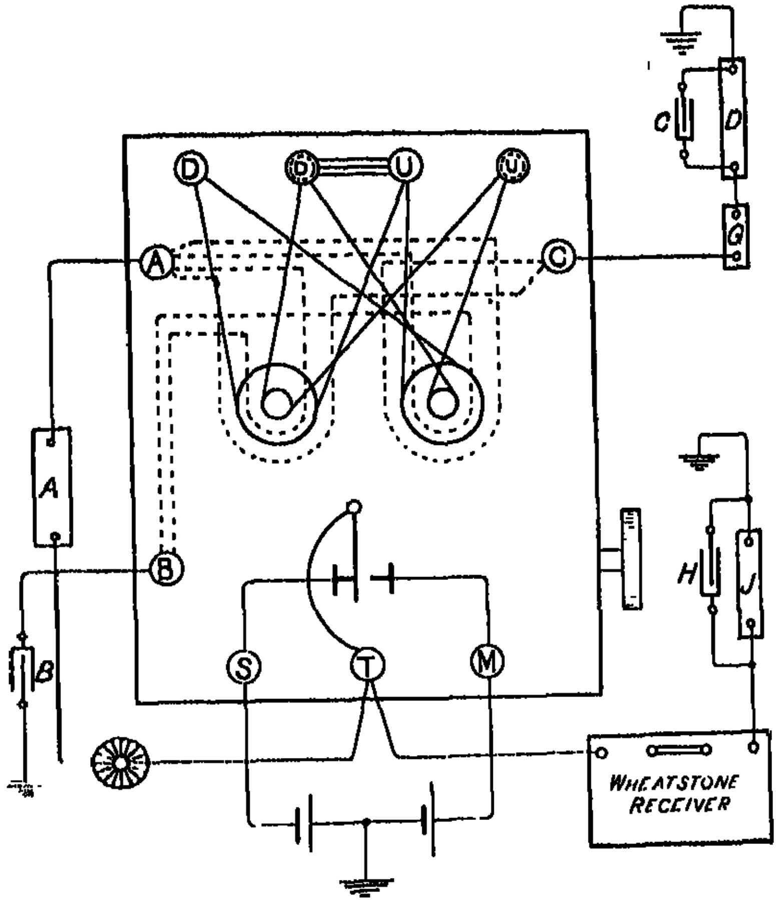


FIG. 119.—Diagram of Relay Standard G.

farads with a shunt of 12,000 ohms, the auxiliary coil circuit being open.

Auxiliary Coils.—For repeating at the rate of 300 words per minute, $7\frac{1}{2}$ milliamperes, the conditions being the same as in the preceding test.

Line circuit coils open.

Direction of Winding.—With the positive lead connected to U and the negative to D the relay should operate in the marking direction for the line coils. With positive to C and negative to B of vibrating coils relay should also operate in the marking direction.

Polarising test for line and also for vibrating coils, 250 milliamperes.

Differential Test Line Coils (series), 250 milliamperes, positive pole applied to D negative to (D) U, and (U) connected together. Line coils (parallel) 200 milliamperes, positive pole to U and (D) connected together and negative to (U) and D connected together.

Vibrating coils (parallel), 200 milliamperes, positive pole to A negative to C and B connected together.

The insulation resistance between coils and coils and frame should be not less than one megohm with 100 volts.

Relay D, 200 ohms (non-polarised).—For use on intercommunication switch. The coils (100 + 100 ohms) are wound with 6 mils single silk-covered tinned copper wire, and the coil ends are led out by means of 12 mils silk-covered tinned copper wire and soldered to the insulated collets which should be friction tight in the base.

The relay should repeat Morse signals with a current of 2 milliamperes and be capable of being biassed so as not to work with 15 milliamperes. The relay should be capable of adjustment, so that while not responding to a current of 6 milliamperes it will repeat Morse signals (key speed) with a current of 8 milliamperes. After the current has been increased to 100 milliamperes for 15 seconds the relay should work with a current of 8 milliamperes but not with 6 milliamperes and without readjustment. The traverse screw should have 100 threads per inch and should work freely and without shake.

Relay Non-polarised B, 200 + 200 ohms.—The coils are double wound with single silk-covered 5 mils wire. The relay should operate with 6 milliamperes. When the adjusting spring is fully extended it should be strong enough to prevent the armatures from being attracted when a current of 12 milliamperes is flowing through the coils, the distance between the armatures and pole pieces for the operating test remaining unaltered. The armatures should be entirely unaffected when the coils are connected up for differential tests as follows :—

Differential Series.—Terminals U and (U) connected together and a current of 100 milliamperes passed through the coils from terminal D to (D).

Differential Parallel.—Terminals (D) and U connected and D and (U) connected, and a current of 200 milliamperes passed through the coils from (D) and U to D and (U).

The iron cores of the electromagnets should be turned from a

20*

solid bar of the best Swedish iron, and after thorough annealing should not show a trace of residual magnetism after a current due to an E.M.F. of 50 volts has been sent through the coils on short circuit. The two parts of the soft iron armature should be well separated magnetically by means of the brass spelter used to braze them together, and the iron should not be overheated. The tongue should be of hard-rolled nickel silver and be dovetailed into the platinum end piece which should be in line with the platinum ends of the contact screws. The contacts in the screws should be of plain circular platinum wire 64 mils diameter inserted into a circular flat-bottomed hole and then soldered into position. The wire should project $\frac{1}{16}$ inch, and the part within the screw should be $\frac{1}{16}$ inch. The platinum end piece should be $\frac{15}{32}$ inch long. The brass links on the terminals should not be lacquered. The spiral connection wire between the base plate and the axle should be of soft copper 4 mils in diameter. The covers should be interchangeable and pass freely over the top plates and be a true fit on the bottom plates. The screw adjustment for the spiral spring should be carefully fitted so that the motion of the sliding nut may be reversed by the slightest reversal of the motion of the screw. The base should be of well-seasoned mahogany thoroughly polished on the top side and treated with polish on the underside. The metal work under the base should not project beyond the base level when the terminals are screwed home. The iron capstan headed screws in the contact blocks should clamp the contact screws before the slots in the blocks are closed. The armatures should be well clear of the coil cheeks and bottom plate. The pivots should be well polished and fit easily but without side shake. The bottom pivot should be well rounded so as to present a small surface to the steel end plate which should be dead hard and well polished. The tongue piece should be securely soldered to the axle in such a position that when the armatures are 10 mils from the cores the tongue will be central between the contact screws. The spring adjustment should work smoothly and without shake.

The schedule on opposite page gives the operating details of the various telegraph relays used by the Post Office.

Sounders, 20 ohms.—For primary battery and low voltage circuits. This sounder is shunted with a non-inductive (i.e. double wound) shunt to provide an alternative path for the inductance discharge of the electromagnet and thus to protect the contacts of the relay by preventing sparking. The coils are 21 ohms in resistance (single silk-covered copper wire 14 mils diameter), and the shunt 420 ohms (single silk-covered eureka or platinoid wire $5\frac{1}{2}$ mils diameter). The armature should be adjusted so that when it is in the attracted position it is 10 mils from the cores and the upper limiting stop screw is 10 mils from the lever. With this adjustment the sounder should work satisfactorily with a current of 55 milliamperes and allow of the tension spring screw being turned through three complete revolutions without interrupting the working. The stop or limiting

TELEGRAPH RELAYS.

N.B.—Where polarising currents are specified they should be applied for 15 seconds in the *spacing* direction. The figure of merit and other tests should be applied *after* the polarising current.

Type.	Resistance Ohms.	Current Milliamperes.			Remarks.
		Figure of Merit.	Differential.	Polarising.	
		[P = parallel.	S = series.]		
Polarised standard A	200 + 200	0·5.	100S. 200P.	—	—
Do. do. B	100 + 100	Key speed, 0·5. Fast speed, 17·5 (400 w.p.m.).	250S. 200P.	250	—
Do. do. (Neutral.)	100 + 100	Do. (Springs removed.)	250S. 200P.	250	—
Do. (Rectangular base)	100 + 100	Same as standard B.	250S. 200P.	250	—
Polarised standard C	50 + 50	12·5 biassed against 25.	100S. 200P.	250	—
Do. do. G	100 + 100 (line coils).	Key speed, 0·5 (vibrating coils open). 400 w.p.m. 7.5 (vibrating coils open).	250S. 200P.	250	—
	100 + 100 (vibrating coils).	300 w.p.m. 7·5 (line coils open).	200P.	250	—
Murray . . .	16	400.	—	—	—
Non-polarised B .	200 + 200	6·0 and biassed against 12.	100S. 200P.	—	—
Do. C .	100 + 100	4·5 and biassed against 10.	100S. 200P.	—	—
Do. C .	500 + 500	3·0 and biassed against 8.	100S. 200P.	—	—
Do. D .	200	Responds to 8 but not to 6. 2·0 and biassed against 15·0.	—	100	—
Do. D .	100 + 100	Do.	50S.	100	—
Gulstad . . .	800 + 800 (line). 150 + 150 (vibrating).	Key speed (line), ·043S. ·058P. 350 w.p.m. ·050S. ·063P.	—	—	—
		Do. (vibrating), ·054 S. 350 w.p.m. ·088.	—	—	—
Baudot . . .	200	Do. 1·5S. 400 w.p.m. 17·5S.	200P.	—	—
8 B . . .	500 + 500	10·0P.	—	—	—
8 C. . . .	10 + 10	30·0P.	—	—	—

screws should be flat at the end—not pointed—and the ends should be free from lacquer. The striking parts of the lever should also be free from lacquer. The coil bobbins should be tight on the cores, and the cores should be screwed and steady pinned to the yoke.

The coils should be evenly wound and the bobbins filled. Where the ends of two coils are joined together they should, after being soldered, be covered with a silk braiding to prevent contacts. The pivots should be in alignment, well burnished and have sufficient end shake to prevent binding. The adjusting spring should be made from hard-drawn nickel silver wire 28 mils in diameter and should have twelve turns, pulled out just clear of each other. The total length, including the two loops should be $\frac{3}{4}$ inch. Cheese-headed terminal screws No. 2 have superseded the milled-headed terminals. The resistances at 60° F. should be within 1 per cent. of the nominal value. The sounder feet are spaced to gauge.

Sounders, 900 *ohms*.—For universal battery working and accumulator and high voltage batteries generally. The electromagnet coils are 1000 ohms in resistance, and a non-inductive shunt of 9000 ohms is fitted to take the inductance discharge of the coils as in the 20 ohm sounder. Except that the operating current of the 900 ohm sounder is 11 milliamperes the notes under 20 ohm sounders apply to this sounder.

Sounders, Polarised, D.—For use on central battery circuits. The several types of this sounder are shown in the schedule below together with the operating currents. The following notes apply to all types. There should be an air gap of exactly $\frac{1}{32}$ inch between the heads of the core fixing screws and the face of the permanent magnet. The permanent magnet should be made of tungsten steel and when fitted with a keeper of the same cross-section as the magnet limbs should lift a weight of not less than 6 lbs. The normal adjustment of the regulating spring should be such that the armature will if so placed remain in either the up or down position when no current is flowing. The upper limiting stop should be either fixed by a lock nut or friction tight in a tapped and sprung hole.

The upper limiting stud should be screwed and adjusted so that a space of 16 mils is left between the face of the stud and the lever when the armature is depressed. The limiting stud should be provided with tommy holes to enable its position to be varied with respect to the armature lever. The lower limiting stud should be adjusted so that when the armature is depressed there will be an air gap of 8 mils between the armature and the cores of the electromagnet.

There should be a clearance of not less than $\frac{1}{16}$ inch between the terminal plates, which are recessed into the base, and the face of the permanent magnet. The spiral tension spring should have 12 convolutions and be adjusted so that all the convolutions are just clear of each other when free from tension. The total length of the springs with the two end loops should be $\frac{3}{4}$ inch.

The resistance of the coils should be marked in clear white figures on the side of the wood base facing the observer when viewed with the adjusting screw of the sounder on the left. The left-hand terminal (viewed with the terminal end towards the observer) should be marked + and the right-hand terminal —.

The north seeking pole of the permanent magnet should be notched on the edge and should be placed under the core which is on the same side of the sounder as the terminal marked +.

The cores of the electromagnet, the supporting bushes and fixing screws and the armature should be of the best Swedish or equally good soft iron, properly annealed and not tooled or filed after the annealing process. The surfaces should be wiped and then lacquered to prevent rusting. The grub screw in the tension pillar should clamp the regulating screw so that when the spring adjustment is made the regulating screw will be firmly clamped in position. The head should be flush with the surface of the pillar or sunk slightly below it when the screw is screwed home. The tapped holes for the clamping screws in the brass footplates should terminate in plain holes in the wood base, and the latter should be deep enough to allow the screws to clamp tightly.

Operating Current.—With the armature and limiting stops adjusted as set forth above and with the normal adjustment of the spring the sounders should work well on a double current circuit with the current values shown in column 3 of the following schedule and with the remaining range of spring tension with those given in column 4.

Polarising Test.—A spacing current of the value given in column 5 should be applied to the sounders for 15 seconds and then be switched off without reversing. With the normal spring tension the sounder should respond after this polarising current to Morse signals with the minimum operating current.

Differential Test.—With the positive pole of the battery joined to the middle terminal and the negative to the two outer terminals connected together the sounder should show no signs of response when total currents of the value given in column 6 of the schedule are reversed at key speed.

SCHEDULE.

Type of Polarised Sounder D.	Resistance Ohms.		Operating Current.		Polarising Current.	Differential Current.
	Coils.	Shunt.	Minimum.	Maximum.		
	(1)	(2)	(3)	(4)	(5)	(6)
100 + 100 ohms.	100 + 100	*nil.*	6 ma.	*nil.*	60 ma.	300 ma.
500 + 500 „	500 + 500	„	*2 to 30 „	50 ma.	50 „	200 „
500 + 500 „ (3 terminal)	„	„	* „ „	„ „	„ „	„ „
2000 „	2308	15,000	2·5 „	25 „	25 „	*nil.*
4500 „	5408	27,000	2·0 „	20 „	20 „	*nil.*

* Between these limits without alteration of adjustment.

Relaying Sounders, 30 *ohms,* 40 *ohms,* 500 *ohms, and* 900 *ohms.*—The coils should be wound with silk-covered copper wire, and the

shunts double wound with silk-covered platinoid wire, the details being as follows :—

Resistance	30	40	500	900 ohms.
" coils	60	44	1000	1000 "
" shunts	60	440	1000	9000 "
Coil wire (copper)	9	11	—	4 mils.
Shunt wire (platinoid)	11·5	6	—	3 "

The resistance at 60° F. should be within 1 per cent. of the nominal value.

Figure of Merit Tests.—The armature when in the attracted position should be 10 mils from the cores of the electromagnet, and there should be 10 mils between the lever and upper contacts. The sounder should work reliably with the figure of merit current, in either direction, when the spiral spring is adjusted through a range of three complete turns of the adjusting screw.

	Operating Current.	Polarising Current.	Differential (Total Current).
30ω sounder relaying	60 ma.	330 ma.	—
40 " "	40 "	250 "	—
500 " "	20 "	30 "	—
900 " "	10 "	33 "	—
500ω + 500ω sounder (polarised) relaying	Key speed ½ ma. 300 w.p.m. * 17·5 ma.	50 "	200 ma.

* 60 volts through an external resistance of 2430ω, 1600ω of which are shunted by a 2 mfd. condenser.

With the tension of the spring at the higher limit, the polarising current for each relaying sounder should be applied to the coils for 15 seconds after which the armature should be reliably attracted when the appropriate operating current is applied to the coils in the opposite direction. Also with the tension of the spring at the lower limit the armature should properly restore on the cessation of the polarising current, the latter being applied for 15 seconds. The local contacts should be of platinum wire 80 mils in diameter, soft soldered into plain holes $\frac{1}{16}$ inch deep, the wire also should project $\frac{1}{16}$ inch, i.e. the total length of the wire should be $\frac{1}{8}$ inch. The cores and armature should be of Swedish iron thoroughly annealed. The armature should be placed symmetrically with regard to the cores of the electromagnet and parallel with the ends. The terminal screws should be made from hard-drawn brass.

The low resistance relaying sounders are used on circuits worked from primary batteries, and the high resistance relaying sounders

on circuits worked from secondary batteries. The polarised 500 + 500 relaying sounder is used as a relay in place of standard relay B on plus circuits of underground loops. It is not so susceptible to inductive interference as relay standard B.

Polarised Sounder B, 4500 ohms.—The coils should be single wound with 4½ mils single silk-covered tinned copper wire to a total resistance of 5400 ohms, that is, 2700 ohms each coil. The outer layer should consist of 14 mils double silk-covered tinned copper wire, and the same should be used for leading out the coil ends to the terminals. The shunt coil should be double wound with 3 mils silk-covered platinoid wire to a resistance of 27,000 ohms and the coil ends should be terminated with 14 mils double silk-covered tinned copper wire as above.

The resistance of the sounder should be within 1 per cent. of the nominal value at 60° F.

The armature and cores of the electromagnet should be of best Swedish iron or equally good iron properly annealed and should not be tooled or filed after the annealing process. The surface should be wiped and then lacquered to prevent rusting. Stop pins of No. 16 brass wire $\frac{1}{16}$ inch in length should be inserted in the ends of the cores with 15 mils projection so as to prevent the armature from striking the cores. A paper washer 6 mils thick should be fitted between the cores and yoke of the magnet. The sounding pieces should be fitted with two small brass washers $\frac{1}{32}$ inch thick immediately under the heads of the fixing screws. The total play of the striker between the stop pins should be $\frac{1}{16}$ inch when the sounding pieces are in an upright position. A small rubber washer ⅜ inch diameter and 100 mils thick should be fitted centrally under each sounding piece, and the dial should be recessed so that the rubber is half in the dial and half projecting. The armature and the striker should be rigidly fixed upon the axle at right angles to each other. The coils should be joined up so that when a battery is connected to the instrument the striker will deflect towards the side to which the positive pole of the battery is attached.

Figure of Merit.—With the striker adjusted centrally between the stop pins the instrument should work well when a current of 1 milliampere is reversed through the coils and shunt. It should also work well and without readjustment when the current is increased to 20 milliamperes.

Sounder Polarised C, 200 + 200 ohms.—Used on double current circuits. Two coils each of 100 ohms connected in series should be joined to the two top terminals and two similar coils to the two bottom terminals. The top terminals should correspond to the front terminals of those sounders of which the terminals are arranged horizontally.

Figure of Merit.—With the coils joined in series, as shown in Fig. 120, and with the positive pole of the battery connected to the top right terminal, the striker should be deflected to the right with a current of 2 milliamperes. With the coils joined in opposition,

as shown in Fig. 121, the striker should not operate with a current of 100 milliamperes. A rubber buffer should be fitted at the back of the right-hand plate.

Sounder Double Plate, 20 *ohms*.—For use with primary batteries. Coils 21 ohms, shunt 420 ohms, galvanometer 30 ohms. When the hammer-head attached to the armature lever touches the sounding plate the armature should be 10 mils distant from the cores of the electromagnet.

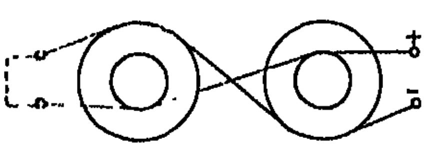
Operating current 73 milliamperes.

The galvanometer needle should deflect to the stop pins with 9·3 milliamperes.

The armature axle should be of hardened steel tempered to a straw colour and polished. The pivots should be well finished.

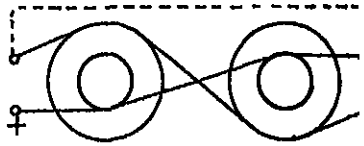
The sounder fitted with a steel sounding plate should be fitted on the left and that with a brass sounding plate on the right.

The armature and cores of the electromagnet should be of best Swedish or equally good iron properly annealed. The oxide coating after annealing should not be removed except where contact is



Coils in Series.

Fig. 120.



Coils in Opposition.

Fig. 121.

made between the cores and yoke. The coils should be wound with 12 mils single silk-covered copper wire to a resistance of 21 ohms.

The ends of the coils should be brought out by means of thicker wire 25 mils diameter.

Sounders Double Plate, 900 *ohms* (for secondary cell working).—Coils 1000 ohms, shunt 9000 ohms. In other respects similar to sounders double plate 20 ohms. Operating current 10 milliamperes.

Sounders, Vibrating Military, with Key.—Used on faulty submarine cables for signalling purposes.

The two windings of the electromagnet should be joined in parallel and induce opposite poles at the armature ends of the two cores.

The inner ends of the windings should be soldered to the cores, and the cores should be connected together by means of a brass plate and connected to the terminal marked ML. The outer ends of the windings should be connected to the terminal marked TB. The resistance of each coil should be 20 ohms and the resistance measured between the terminals marked TB and ML should consequently be 10 ohms. A brass block should be fitted to the free end of the steel spring attached to the armature. The insulated contact of the vibrator should be joined to the front contact of the key and the bridge to the terminal marked B. Two adjusting pins should be provided, and these should be screwed into brass plates

in the wood base when not in use. A sharp note should be produced when a current of 125 milliamperes is applied to the coils and no further adjustment should be necessary when the current is increased to 500 milliamperes.

Wheatstone Automatic Transmitters.—Practically all the transmitters used by the Post Office are made in the Post Office factories. The electrical mechanism is shown in Fig. 122. The transmitter

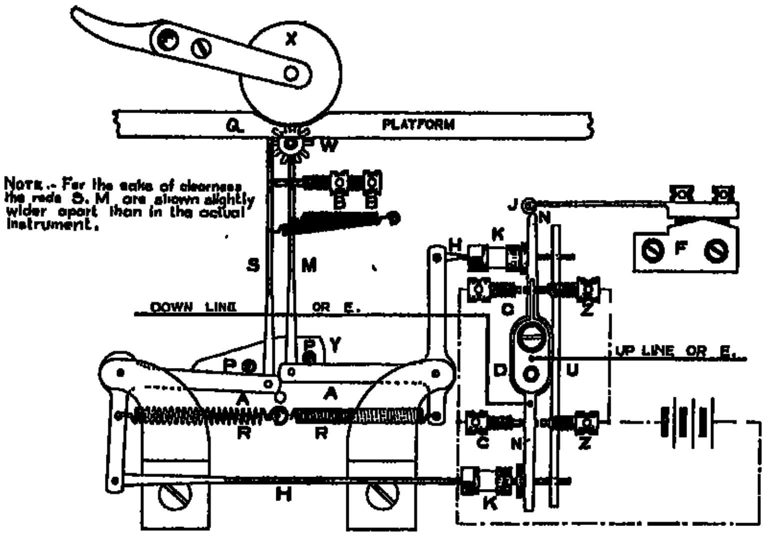


FIG. 122.—Diagram of Electrical Mechanism of Wheatstone Transmitter.

is tested at the lowest and highest speeds, and for this purpose is connected in the circuit shown in Fig. 118. With the lever at "slow" the transmitter should pass not more than 12 feet of slip per minute and with the lever at "fast" not less than 10 feet in 10 seconds. Good clear signals should be produced on the standard receiver when a perforated slip is passed through the transmitter at any speed between the above limits, but especially *at* the limits with the figure of merit current in the receiver. The transmitter should admit of the same slip being run at least four times without the slip being mutilated as would be the case if the rods which pass through the slip were not properly adjusted. An insulation resistance test with 100 volts should be taken as follows :—

Terminal E against other terminals with switch lever at "on" and at "off" and at slow and fast speeds.

Terminal	C	against	terminal	Z
"	U	"	"	D
"	$\frac{MK}{C}$	"	"	$\frac{MK}{Z}$

with speed lever and switch actuated as above.

The distance between the bottom of the paper roller and the platform should be from 8 to 10 mils. The top ends of the vertical rods which pass through the paper should be flat with slightly rounded edges, and when in their lowest position they should be just level with the upper surface of the platform. When the back vertical rod is at its highest position one tooth of the star wheel should have just passed over the vertical position. A piece of perforated slip should be placed under the paper roller and the roller should be slowly rotated by hand to ascertain whether the ends of the vertical rods pass freely in and out of the holes in the paper, and without damage to the edges of the holes. The vertical rods are adjusted by means of two steel screws beneath the platform. The back vertical rod should be quite clear of the star wheel collet.

The battery contact screws and the nuts and collets on the horizontal rods should be adjusted so that the compound lever will be rocked uniformly from side to side. Marking and spacing signals of equal duration should be obtained when the transmitter is running reversals. Proof of this will be indicated by the testing galvanometer needle—temporarily put in the circuit for the purpose—showing equal deflections on each side of zero at slow speed and remaining at zero at high speed.

The action of the compound lever should be positive and definite and when at rest the lever should make good connection with two of the battery contacts. The driving weight should weigh 42 lbs. and the driving chain should be 7 feet 6 inches in length. The switch connected to the $\frac{MK}{C}$ and $\frac{MK}{Z}$ terminals should have a brass plate fitted between the connection blocks but not projecting above them to prevent the lever from short-circuiting the battery when the switch is operated. The iron capstan headed screws should cause the front contact screws to be clamped tightly. The "fly," No. 4 pinion, and intermediate nickel silver discs and contacts should be clean. All pivots should be free and oiled.

The lubricating cup on the bearing for the rocker eccentric should be two-thirds full of compressed cotton wool and saturated with best mineral clock oil.

The contacts should be made of platinum. With the lever at "slow" the transmitter should start when the brake is slowly taken off.

Adjustment.—The clamping screws of the contacts should be unscrewed and the contacts equally withdrawn. The two lower contacts should be so adjusted that the compound lever will "snap" with equal pressure on both contacts which should be clamped in this position by tightening the clamping screws. The check nut of the collets on the horizontal rods should be unscrewed and the collets withdrawn so that the latter just fail to engage the lever. The top collet should then be adjusted until it engages the lever sufficiently to push it past the jockey wheel when the collet should be given an extra half-turn and clamped. The lower collet should

be adjusted in a similar manner. The upper contacts should be adjusted with the top of the lever lying to the right of the jockey wheel. The right-hand contact should be adjusted so that a deflection to the right is shown on the galvanometer. The contact should be clamped in this position. The top of the lever should then be pushed over to the left of the jockey wheel and the left-hand contact adjusted until a deflection to the left is shown on the galvanometer. The contact should then be clamped. The final adjustment is best made on the top contacts. Run reversals at slow speed and note the deflections of the galvanometer which should be of the same magnitude on both sides of zero, and when the transmitter is run at fast speed the needle of the galvanometer should remain at zero.

If the galvanometer shows that there is a slight bias—marking to the right, spacing to the left—advancing the bottom collet K on the horizontal rod in the former case or the top collet K′ in the latter case will take it off. The play between the lever and the contacts should be about 5 mils. The jockey wheel J, which is attached to a flat spring mounted on the knife edge F is adjustable by means of two screws which fasten it to its support. It should press with sufficient force on the lever to ensure its prompt travel to the right or left when either of the collets K or K′ pushes it beyond the centre of the jockey wheel. The correct position of the collets K and K′ on their respective screwthreads can be found by running a blank slip through the transmitter when the lever should be unaffected whether resting in its left or right position. The collets should be close enough to the lever to push it over the centre when the slip is removed so as to allow the jockey wheel to complete the movement. The spiral springs S_3 and S_4 must be strong enough to overcome the pressure of the flat spring supporting the jockey wheel. The exact positions of the vertical rods S and M are regulated by the screws BB′. Each rod should be adjusted so that it commences to enter a hole in the slip when the left-hand edge of the hole is clear enough of the left-hand edge of the rod to allow of its passing through freely. If the screws are not in the best position as regards adjustment the rods will catch against the edges of the perforations and the mechanism will not operate satisfactorily whilst the slip will be damaged and "cut up" as it is usually described. The springs S_1 and S_2 pull the rods SM back against the screws B as soon as they are clear of the slip.

The springs are rather light, but they should be capable of exerting sufficient tension to cause the rods to return to their normal positions promptly. When a blank slip is run through the transmitter the rods S, M should be pressed downwards far enough to ensure that the pins PP′ will not operate the bell-crank levers AA′ and consequently the lever DU, Fig. 122 is only diagrammatic.

Wheatstone Receiver (*Spring type*).—Resistance 100 + 100 ohms. Figure of merit key speed (about 25 words per minute) coils in parallel 10 milliamperes. Fast speed (200 words per minute) coils in series 17·3 milliamperes. A battery of 60 volts with an external resistance

of 3260 ohms, 1600 ohms of which are shunted with a 2 mfd. condenser is the usual arrangement. The coils when joined in series should be differential with a current of 100 milliamperes, and when joined in parallel they should be differential with a current of 200 milliamperes. The insulation resistance between the coils and the frame should be not less than one megohm at a pressure of 100 volts. The speed of the slip should not exceed 8 feet per minute with the speed lever at "slow" and be not less than 36 feet per minute with the speed lever at "fast." Clear signals should be obtained on the slip when the key is operated and when the transmitter is run at fast and slow speeds. With a spacing current in the coils the small steel marking disc should not touch the brass inking disc but should pick up the ink by capillary action. The steel disc should pick up ink promptly when the receiver is started at slow speed. When the armature is lightly held over to the marking side (left-hand contact) a plain unbroken line should be made on the slip and the local sounder should be energised. When the adjusting screw is at zero as indicated on the graduated disc the armature should be midway between the pole pieces, and the tongue if lightly pushed to either side should remain there. If it will not remain on either side the screw contacts should be adjusted as follows:—Run the slip at about 15 feet per minute, lightly press tongue against marking contact and screw the marking contact forward until the line on the slip breaks up into a series of dots, slightly withdraw the marking screw contact until a good continuous line is obtained on the slip, then press the tongue lightly against the spacing contact and screw the spacing contact forward until dots appear on the slip. The spacing contact should then be unscrewed till the dots disappear from the slip. It will be found that the tongue will now remain on either contact if placed there. If the graduated disc is turned through an angle of more than 10° it should cause a bias to be given on the corresponding side. With the main spring fully wound up and the speed lever at "fast," the set on the jewel spring should be sufficient to hold the train with the starting lever in the "off" position. The inking discs and contacts should be clean and all pivots should be oiled. The paper wheel and boxwood rollers in the paper drawers should run freely. The electrical tests are taken on the special board, a diagram of which is shown in Fig. 118, the receiver under test replacing the receiver shown.

Wheatstone Receiver (weight driven type usually described as *Receivers train*).—Resistance 100 + 100 ohms. The figure of merit and other electrical tests are the same as for receiver spring above except that the fast speed is 400 words per minute although in practice nowadays these receivers are seldom used at higher speeds than 300 words per minute. The speed of the slip should not exceed 8 feet per minute with the speed lever at "slow" and should be not less than 45 feet per minute at "fast." To set the contacts for the sounder circuit the tongue of the lower armature is adjusted as follows: (1) Set the adjusting screw in its middle position by

counting the number of turns required to screw it from one limiting stop to the other and turning it back through half this number. Turn on the slip and allow it to run at about 15 feet per minute. (2) Lightly press lower tongue against marking contact and adjust the marking screw contact—not the adjusting screw—until a broken line or series of dots only appears on the slip. (3) Withdraw the screw-contact slowly until an unbroken line on the slip is obtained. (4) Lightly press the lower tongue against the spacing contact and adjust the spacing screw-contact until dots begin to be recorded on the slip. (5) Unscrew the spacing screw-contact until the dots disappear from the slip. If the play appears to be excessive the trouble will probably be due to dirty inking discs.

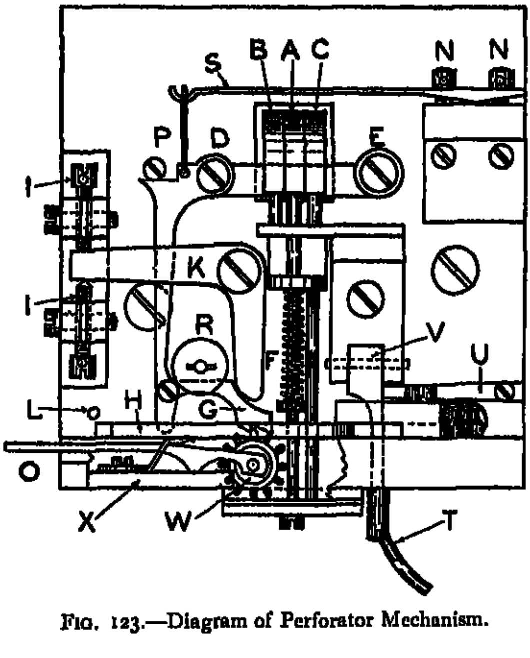


FIG. 123.—Diagram of Perforator Mechanism.

Wheatstone Perforator.—The single type of perforator is arranged to perforate either one or two slips and may be operated by hand. The double type of perforator is arranged to perforate either three or four slips and is used in conjunction with a pneumatic pressure puncher. An expert knowledge of manipulative telegraphy is required in subjecting the perforator to its functional test as the faster the manipulation the more accurate and decisive must the perforator operate. A perforator may operate satisfactorily at a slow or medium speed of manipulation and prove too sluggish when operated at fast speed by an expert telegraphist, the slip being mutilated and unreadable. On the other hand, a perforator may give a

perforated slip that appears to be quite satisfactory, but which fails to transmit signals satisfactorily when run through the transmitter due to the fact that the centre guide holes are not spaced at the correct distances. This defect is sometimes referred to as "out of gauge." The pitch of the guide holes should be exactly one-tenth of an inch, so that if 121 guide holes are made the distance from centre to centre of the outside holes should be exactly one foot. Fig. 123 shows the essential parts of the mechanism. The pitch of the guide holes can be slightly varied by means of the two screws *i i* which act upon the bent lever K moving the end near the pawl G either inwards or outwards. The former increases and the latter decreases the pitch of the guide holes. If the word "telegraph" be perforated on the slip three times with the usual two spacing guide holes between words, but no guide hole after the last letter it will be found to contain 121 guide holes, and if the gauge or pitch is correct it will measure exactly one foot, between the centres of the first and last guide holes. If the perforator is sluggish and will not perforate satisfactorily when tried at a high speed of manipulation it may sometimes be put right by altering the tension of the spring S by means of the adjusting screws NN. If the tension needs increasing as is generally the case, the inner screw should be slightly slackened before tightening up the outer, otherwise there is risk of breaking the small screw. The internal surfaces of the drilled holes in the hollow punches should be perfectly smooth and the chamfer of the front puncher plate should be ground to a polish. The guide holes should be in the middle of the slip and all punches should cut clean perforations quite free from burrs. Where the moving parts pass through slots in the front plate they should move without touching the front plate at any part of their traverse. Especially is this the case with the guide star wheel. Each plunger should be operated and allowed to rise very slowly to ascertain whether the punches and other moving parts return to their normal positions after being operated. Each plunger should be depressed and held down while the others are operated to see that they are quite free. The pawl G should be correctly set so that there is no tendency to ride over or under the star wheel. A steel plate gauge 500 mils wide and 9 mils thick should pass freely through the space provided to take the double slip. This is not shown in the figure. The paper used with the perforator is from 472 to 475 mils wide and from 4 to 4½ mils thick. It is prepared by soaking in hot refined earth nut oil. No useful purpose is served by putting oil on the plungers, and its presence has a deleterious effect on the rubber buffers. Double perforators for perforating 3 and 4 slips are fitted with stronger springs, and to distinguish them from the single type the figure 4 is stamped on the base. They should work satisfactorily on the pneumatic pressure puncher with an air pressure of 10 lbs. per square inch.

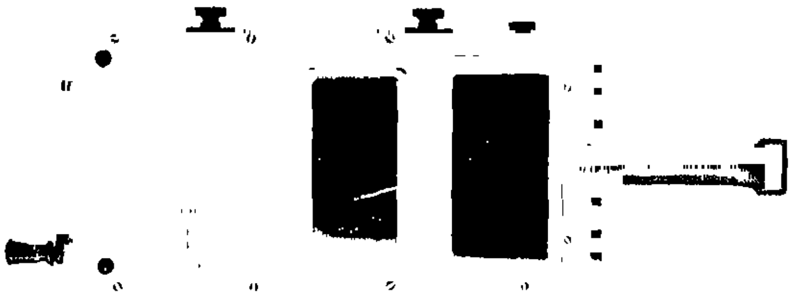


FIG. 121.—Plan View of Bridge Megger.
(Messrs. Evershed & Vignoles.)

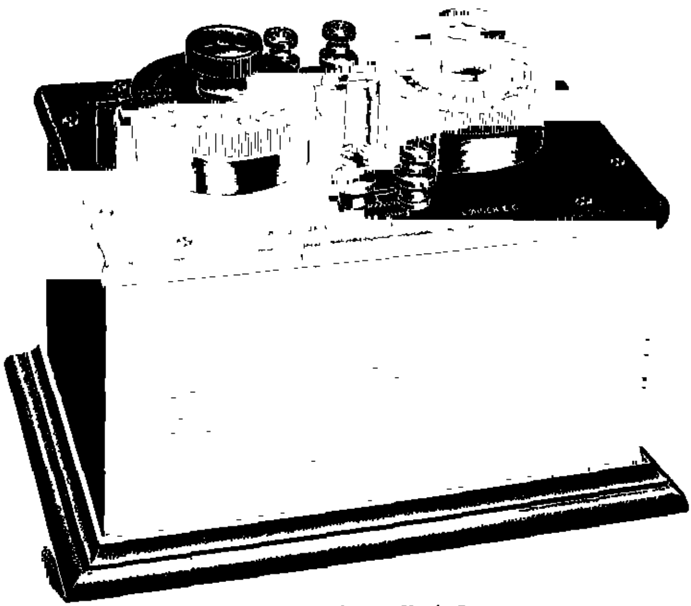


FIG. 142.—Hay-Sullivan Fault Locator.

[See page 334.

CHAPTER XVIII

MAINTENANCE TESTING OF LINES

SIGNALLING or speaking trials to prove whether the wires are in working order are made on all wires every morning usually before 8 a.m. by the operators at the principal Telegraph Offices and Telephone Exchanges, and trunk telephone wires are tried for signals as well as for speech. Any wires that are found to be out of order are noted and advice is sent immediately to the Testing Officer, who proceeds to investigate the cause of the stoppage. In addition tests for insulation resistance and conductor resistance are made periodically before 8 a.m. of all wires more than 50 miles in length. The general practice is to measure the insulation resistance of each wire once a week and the conductor resistance once a month, the insulation resistances being left over in the week that the conductor resistances are measured. Long wires are tested in sections of approximately 100 miles, the test being made from the controlling offices. It is usual to lay down rigidly which of two offices connected by wires is the controlling office and in general the larger office of the two is made the controlling office. When it is necessary to test from an intermediate office, this office tests as far as about 100 miles on each side, and a second intermediate testing office is only required when the wire is over 400 miles in length.

The tests are usually made with a bridge megger, a photograph of which is shown in Fig. 124. The value of the resistance under test is indicated directly in ohms or megohms by a pointer which moves over a scale. The set consists of a generator which may be either hand-driven or motor driven and a moving coil galvanometer. Fig. 125 is a diagram illustrative of the action of the set which is described in the Post Office technical instruction as follows: "The current generated when the armature D of the generator is rotated has two paths open to it. One path is from the positive brush direct to the terminal E and from the negative brush through the 'current' coil A and the resistance coil R_2 to the terminal L. The other path is from the positive brush through the resistance coil R_1 to the coils C and P and thence to the negative brush of the generator. The latter path is unbroken and does not vary in resistance, and the voltage is maintained at a constant value. The field developed in the double or 'pressure' coil C by the passage of a current through it is therefore also constant. The force acting

on this coil, tending to turn it, is directly proportional to the constant difference of potential between the positive and negative brushes. The force acting upon the 'current' coil being directly proportional to the current in the coil itself is inversely proportional to the resistance under test. If this resistance were infinite, the system would be deflected by the force acting on the pressure coil alone, and the pointer would then indicate 'infinity.' The more the resistance diminishes the greater is the amount of current which is allowed to pass through the 'current' coil. Lines of force generated by that current through a soft iron cylinder are at an angle to the lines which pass normally between the pole pieces of the magnets and they increase with the current. The two sets of lines tend to coincide in direction and this potential energy becomes converted into kinetic energy in the only way open to it, that is by producing mechanical action in the movement, not of the pole pieces

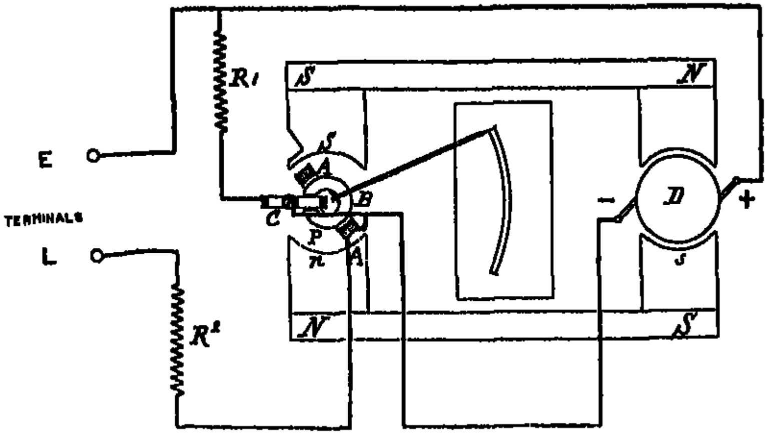


FIG. 125.—Explanatory Diagram of Megger Connections.

which are fixed, but of the movable 'current' coil A. The free rotation of this coil is restrained—apart from friction losses which are negligible—by the action of the 'pressure' coil C which, while a current is passing through it, tries to embrace as many lines of force as it can, and therefore to move over the split cylinder and the projecting horn of the pole piece S. It is against this tendency of the coil C that the coil A has to act; the latter will overcome the former more completely the more current passes through it, that is, the less the resistance under test. The instrument is calibrated accordingly, allowance being made for the resistance of 200,000 ohms in the resistances R_1 and R_2. As the field due to the magnets is permanent, there will always be lines of force passing through the pressure and current coils, but in the absence of current in these coils no distortion of field will take place and consequently there will be no pull upon either coil. When the generator handle is at rest,

therefore, the pointer is entirely free and will remain stationary anywhere on the scale." The internal mechanism is very complex, and no attempt is made to effect repairs in local mechanics' shops, the set being returned to the makers (Messrs. Evershed & Vignoles) for the purpose should any defect develop. The megger should be placed for use on a firm, steady, and level base. The handle must always be turned in a clock-wise direction at about 100 revolutions per minute at which speed the clutch is freed and the voltage remains constant.

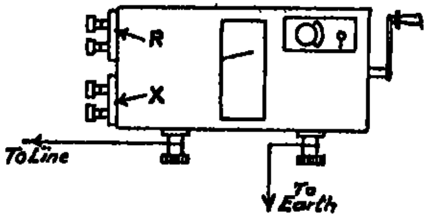


FIG. 126.—Megger Connected for Insulation Test.

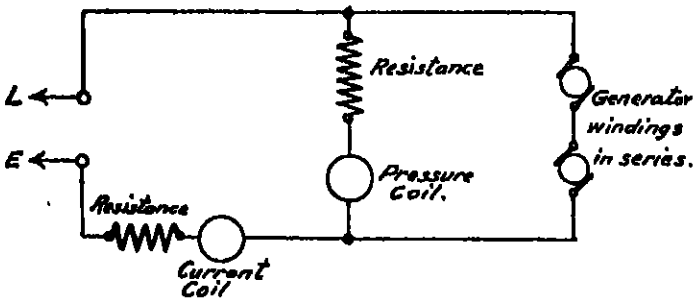


FIG. 127.—Theoretical Diagram of Megger Connections for Insulation Test.

Fig. 126 is a sketch of a bridge megger connected up for testing insulation and Fig. 127 is a theoretical diagram of the connections.

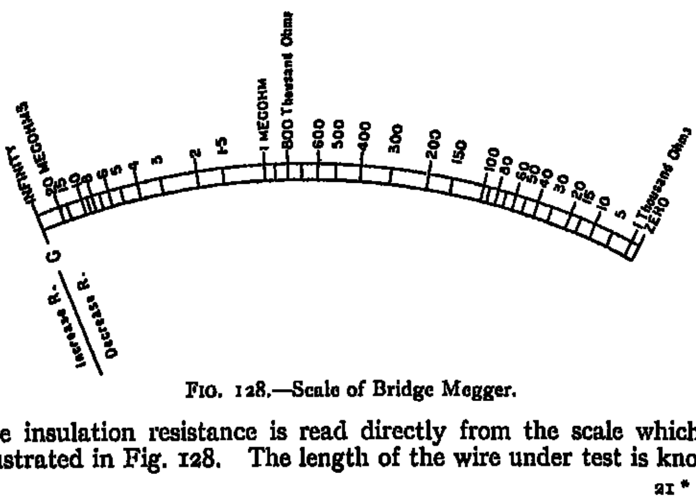


FIG. 128.—Scale of Bridge Megger.

The insulation resistance is read directly from the scale which is illustrated in Fig. 128. The length of the wire under test is known

nd the product of the insulation reading and the length in miles ives the average insulation for a mile of line. For overhead lines, which may include short lengths of underground where the line passes through towns, the minimum average insulation resistance that is regarded as satisfactory is 200,000 ohms for a mile of line, that is to say, the megger reading multiplied by the length in miles should not be less than 200,000 ohms. This is an arbitrary standard that has been used in the Post Office for many years and as a rough approximation is found to give satisfactory results. It is, however, well known in the Post Office, and it has been proved by a series of experiments, that to maintain a wire in best condition for the most exacting requirement—namely, high-speed automatic working—the apparent insulation resistance of the line must not fall below the total conductor resistance. For example, a line of 100 miles in length consisting mainly of overhead work and having say a conductor resistance of 15 ohms per mile will be sufficiently good for fast speed working if the apparent insulation resistance is 1500 ohms, which would give an average result for one mile of 150,000 ohms, the conductor resistance being 1500 ohms.

If R is the apparent insulation resistance in ohms shown by the megger, l the length in miles, R_1 the average insulation resistance for one mile of line, and r the conductor resistance per mile, then

$$Rl = R_1$$

$$R = \frac{R_1}{l} = rl$$

and

$$R_1 = l^2r.$$

Therefore the minimum insulation for a mile of line to provide best conditions for fast speed telegraph working varies directly as the square of the length in miles, and is consequently more difficult of attainment on the longer lines, other conditions being assumed to be equal. Wet weather, proximity to the sea or to chemical manufactories, etc., tend to lower the apparent insulation and considerable discretion is necessary in interpreting the results, but where one wire is much lower in insulation than the others on the same route it is probably indicative of a fault that can be remedied. For trunk telephone lines it is important that the insulation of the two wires forming the metallic circuit shall be approximately the same, otherwise there is likely to be noise on the circuit due to the out of balance of insulation. On telephone circuits having no intermediate offices the average insulation resistance for a mile of line may be as low as 60,000ω without injuriously affecting communication on single wires, and also on metallic circuits provided the loss is fairly uniform throughout. As a general rule it may be laid down that even under the most unfavourable conditions as regards weather, etc., the average insulation for a mile of line should not be regarded as satisfactory if it falls below 60,000 ohms. If temporary crosses of intermediate lengths have been made, as is

sometimes the case on long lines which have developed faults, these crosses are put straight before the tests are commenced so that the tests are always comparable with those taken previously.

Main underground cables are tested monthly by the engineering staff. Certain wires only in each cable are tested, and the same wires are tested regularly, a 250 volt megger being used for the purpose. The maximum direct current which can be safely used on a loaded circuit without adversely affecting the loading coils is 100 milliamperes, and the wires are given distinguishing labels at the test boxes so that the loaded circuits can be readily identified, their labels being of a green colour. Arrangements are made so that the safe current is not exceeded. Circuits are regarded as containing a fault if the insulation for a mile of wire is less than 500 megohms, and on certain important trunk routes special localising tests are made whenever the average insulation is found to have

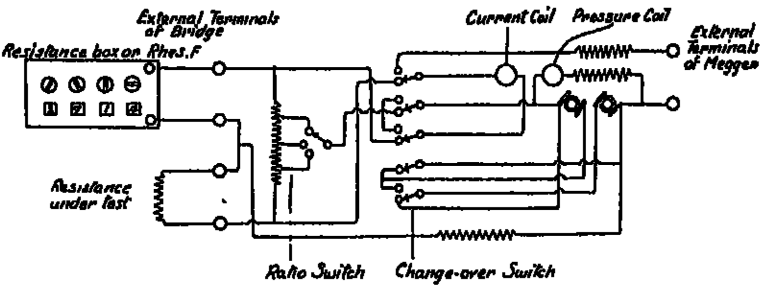


FIG. 129.—Diagram of Bridge Megger Connected for Conductor Resistance Test.

fallen appreciably below the figure usually obtained on these particular routes. The special localising test is usually a loop test (described later) taken with a high voltage.

The conductor resistance tests are taken with the bridge megger, the necessary change in the internal connections being made by means of a two-way change-over switch which can be set at either megger or bridge. The voltage in the bridge position of the switch is 125 and in the megger position 250. There is also a ratio switch providing ratios of 1, 10, or 100. Fig. 129 is a diagram of the internal connections and the connections to the additional resistance box and wires under test. When the ratio switch is on I the value of the resistance under test is given directly by the additional resistance box, when on 10 and 100 the values of the resistances under test are obtained by *dividing* the resistance shown in the additional resistance box by 10 and 100 respectively. If only one wire connects two towns the distant end is earthed and one terminal of the bridge megger is earthed, but if a second wire is available the wires are connected at the far end and the connections are then as shown in Fig. 130, and the theoretical connections as shown in Fig. 131. The change-over switch is set to bridge, the ratio

switch to 1, and the dials of the additional resistance box to zero. The generator handle is then turned *slowly* in a clock-wise direction. The needle will take up a position off the scale and above the line marked G, that is to say, on the side marked

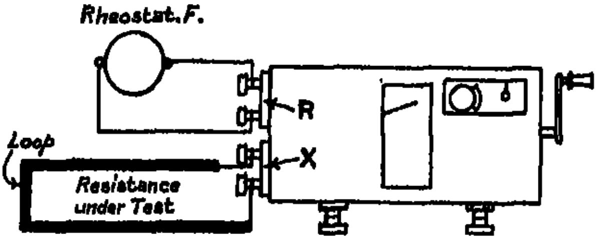


FIG. 130.—Connections to Bridge Megger for Conductor Resistance Test.

"Increase R." While turning slowly with the right hand raise the value of R step by step by turning the resistance switches beginning with the thousands switch and going on with the hundreds, tens, and units until the index reads accurately on the line G. Then

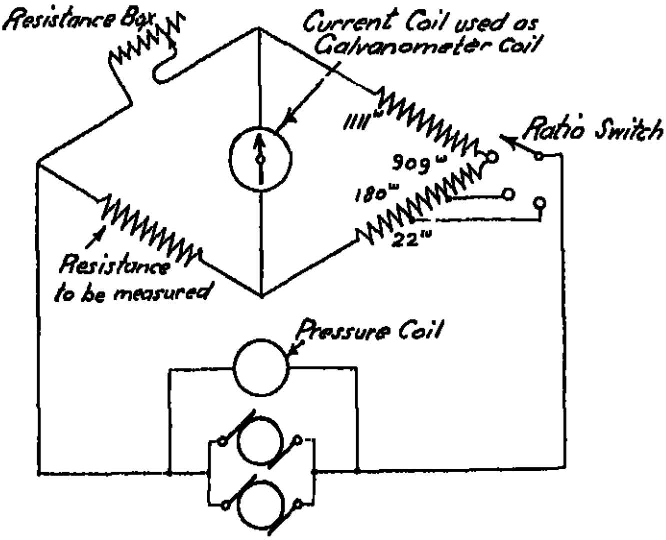


FIG. 131.—Theoretical Connections of Bridge Megger Connected for Conductor Resistance Test.

turn the handle at full speed to obtain the maximum sensitivity and finally adjust R. Read the result shown by the figures on the resistance box. This is the value of the resistance under test. If the resistance is under 100 ohms a more accurate result may be obtained by putting the ratio switch on 10 or 100. Put all the dials to zero and obtain a fresh balance. The value of the resistance

under test is now equal to the box reading *divided* by 10 or by 100 respectively.

For resistances over 10,000 ohms it is necessary to connect the resistance box to X and the resistance under test to R and the ratio switch to 10 or 100. The balance is obtained as previously described, but in this case the box reading is *multiplied* by 10 or 100 respectively and "Increase R" becomes "Decrease R" and "De-

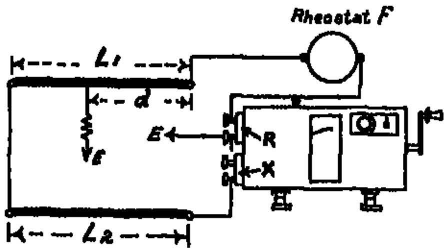


FIG. 132.—Varley Loop Test. Bridge Megger Connections.

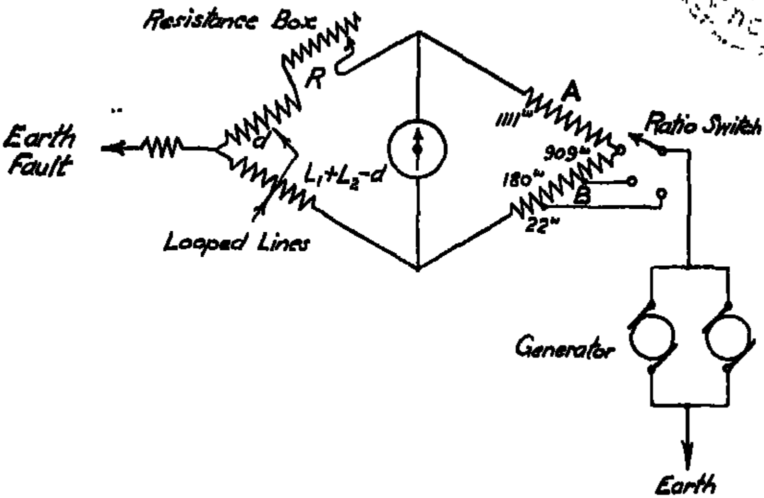


FIG. 133.—Theoretical Diagram of Bridge Megger Connections for Varley Loop Test.

crease R" becomes "Increase R" since the relative positions of the box and resistance under test have been transposed. If the resistance is considerably above 10,000 ohms it may also be determined by connecting up as shown in Fig. 126 and reading the result direct from the megger scale. The latter method is quicker but not quite so accurate as the bridge test.

The question of the renewal of old wires is generally taken up when the resistance reaches 25 per cent. in excess of the value when

first erected, allowance being made for probable temperature variations due to the time of year when the tests were made.

Fault Testing.—When the testing officer at a controlling office decides to withdraw a faulty circuit for localisation test he instructs all the testing offices concerned and these offices test their respective sections, reporting the results to the controlling office, where meanwhile a test of the section proper to itself has been made. In the event of a heavy breakdown due to storms, etc., the controlling office asks the distant stations to co-operate in ascertaining whether more than one fault exists on any line. It is not usual to withdraw a circuit for localisation test unless the fault has been on 15 minutes. Terminal offices try to speak or signal on all faulty circuits once every 15 minutes so that the wires may be brought into use immediately the faults have been cleared. In a localisation test the wire is proved to the testing point nearest to the middle of the length. The next test is made to the middle of the half found to be faulty and so on as far as testing points permit. The Engineering Department is at once advised of the name of the section to which the fault has been localised, and in those cases where the distance between testing points is considerable a loop test is made by the testing officer to ascertain the position of the fault before sending an advice to the Engineering Department. It is now the practice to lead in trunk circuits to offices as little as possible and to provide by means of fuse insulators and dummy fuses facilities for looping and disconnecting on the poles, so as to keep the losses due to leading-in as small as possible. In these cases the linemen in the faulty section are instructed to connect up or disconnect the wires at the fuse insulators as required by the testing officer. For an earth fault the Varley loop test is used when a second wire is available, and the test is made by means of the bridge megger. The lines are looped at the distant end and the resistance of the loop is measured. Let this resistance be L ohms. The connections to the bridge megger are then altered to those shown in Fig. 132, the diagram of connections being shown in Fig. 133. Then remembering that $L = L_1 + L_2$

$$\frac{A}{B} = \frac{R + d}{L - d}$$

$$d = \frac{AL - BR}{A + B} = \frac{L - R\dfrac{B}{A}}{1 + \dfrac{B}{A}} \text{ ohms.}$$

When the ratio switch is on 1 then B = A and

$$d = \frac{L - R}{2} \text{ ohms.}$$

When the ratio switch is on 10 or 100 then $\frac{B}{A}$ equals 10 or 100 respectively, and these ratios are used when the loop is one of low

resistance. Since $(L - d)$ can never be less than $\frac{L}{2}$ it is usually convenient to use the same ratio of $\frac{A}{B}$ for the two measurements.

As the resistance of the earth fault is in the battery or when the bridge megger is used, the generator circuit, it does not come into the calculation of d, its only effect being to reduce the current in the bridge circuits.

Murray Loop Test.—When the loop to be tested is of very low resistance—say 10 ohms—it is advisable to use the Murray loop test which is somewhat more sensitive than the Varley loop test used in the foregoing, and this practice is generally followed in testing short sections of underground cable. For the Murray loop test

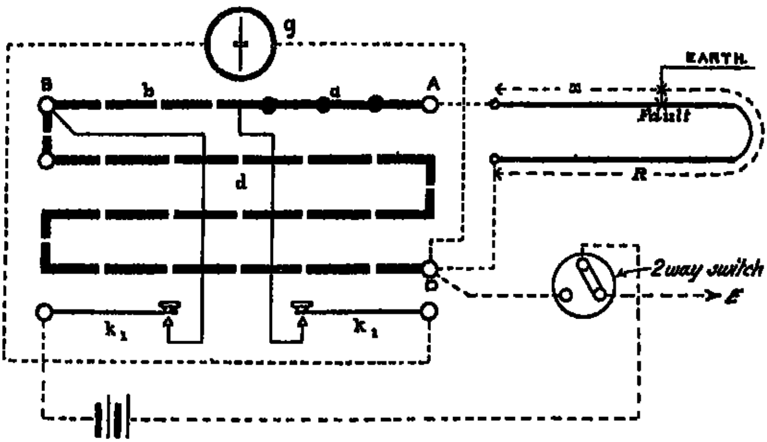


FIG. 134.—Diagram of Bridge Connections for Murray Loop Test.

a Wheatstone bridge is necessary because facilities must be provided for plugging up one ratio arm of the bridge. The resistance of the loop is first measured. The ratio arm a is then plugged up and in this test the galvanometer and battery connections are made as shown in Fig. 134. The theoretical diagram is shown in Fig. 135. Let L ohms be the resistance of the loop, then when balance is obtained we have

$$\frac{b}{d} = \frac{x}{R},$$

but

$$L = R + x,$$
$$R = L - x.$$
$$\therefore \frac{b}{d} = \frac{x}{L - x},$$
$$bL - bx = dx,$$
$$x = \frac{bL}{b + d} \text{ ohms.}$$

Where a " dry " joint in a wire—that is, a joint where the solder has not effectively taken, so that it is equivalent to an unsoldered joint—or an unsoldered joint causes the resistance to be unsteady in value it is advisable to use the ordinary Wheatstone bridge and a low voltage battery as a high voltage is liable to conceal the defect. Prolonged observation of the balance is generally necessary in these

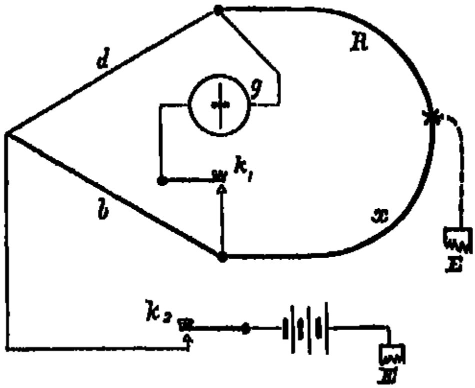


FIG. 135.—Theoretical Diagram of Connections for Murray Loop Test.

cases, as the wire only shows the higher resistance intermittently due to vibration by the wind, etc. The obvious procedure when a fault of this nature is indicated is to test the wire in sections localising to the middle points of the length as before described in the localisation tests.

In testing for the distance of a contact between two wires it is necessary to know the total resistance of one of the wires. This

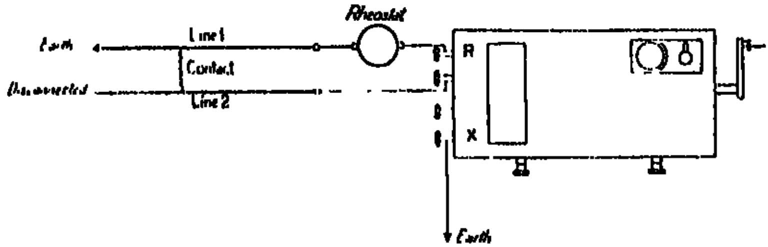


FIG. 136.—Bridge Megger Connections for Measuring the Distance of a Contact between Two Lines.

can be obtained from the records of the periodical tests. This wire is earthed at the distant end and joined to the resistance box and bridge megger at the testing end, whilst the wire in contact with it is disconnected at the distant end and joined to the second terminal of the bridge megger at the testing end as shown in Fig. 136. A theoretical diagram of the connections is shown in Fig. 137. If

the total resistance of the earthed wire as taken from the records is L ohms, and the resistance of the length from the testing end to the contact is X ohms then the resistance of the remainder of the

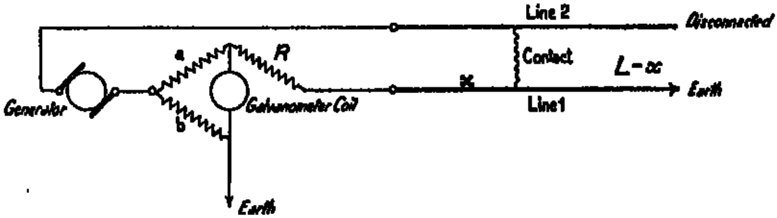


FIG. 137.—Theoretical Diagram of Bridge Megger Connections in Measuring the Distance of a Contact between Two Lines.

wire is (L − x) ohms. When balance is obtained let the resistance shown in the resistance box be R ohms, then—

$$\frac{A}{B} = \frac{R + x}{L - x},$$
$$AL - Ax = BR + Bx,$$
$$x = \frac{AL - BR}{A + B} \text{ ohms.}$$

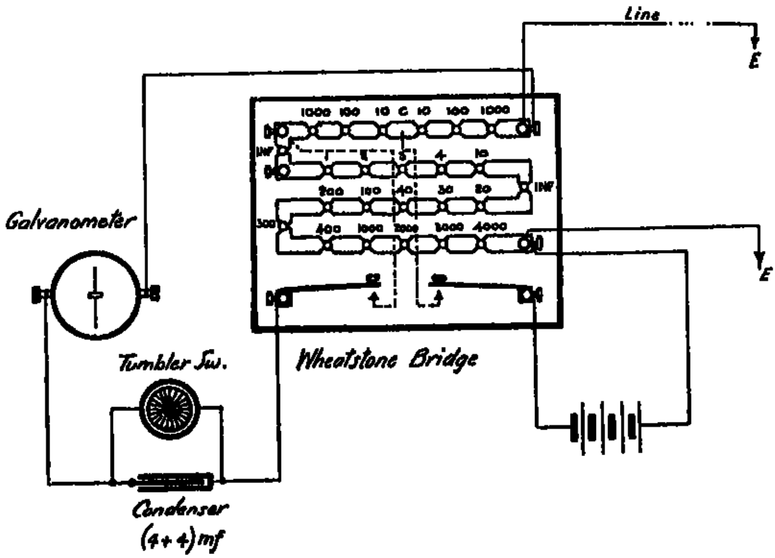


FIG. 138.—Connections of Bridge in Testing Earthed Line when Earth Current is Flowing.

Since there are two earths—one at the testing end and one at the distant end—in series with (L − x) the value of L should be

y disconnecting the other wire from the bridge megger
disconnected at the far end), joining the freed connection
;e megger to the testing end of L, and measuring the
f the earthed wire. The value of L measured in this
robably be greater than that obtained from the records
ifference should be subtracted from the value found for

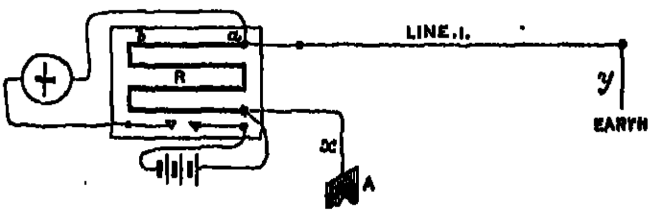


FIG. 139.—Diagram of Bridge Connections used in Testing Earth Plates. First Test.

L − x. The difference is due to the resistance at the two earths. If earth currents are present it will be necessary to use a Wheatstone bridge and condenser as shown in Fig. 138. The galvanometer key is kept depressed whilst balancing and the resistance in the third arm of the bridge is varied until there is no movement of the pointer due to the depressing of the battery key. The usual bridge formula

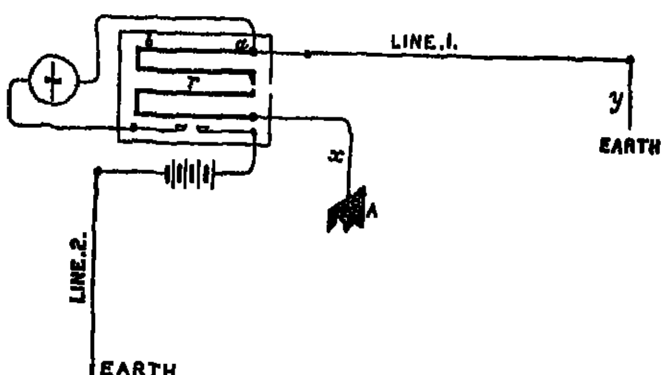


FIG. 140.—Diagram of Bridge Connections used in Testing Earth Plates. Second Test.

holds. The galvanometer under these conditions is not very sensitive, but results are obtainable of fair accuracy and may be relied upon to within 2 per cent. The absence of electromagnets and condensers in the line is assumed in this test, otherwise the charge and discharge of these would prevent a balance being obtained. If, however, the earth current is quite steady in value no condenser will be required as the bridge galvanometer can be used as though zero were at the

point indicated by the steady value of the earth current, and the galvanometer key being kept depressed all through, the balance is obtained by altering the third arm of the bridge until no movement of the pointer is found on depressing the battery key.

Earth Plates.—On telegraph lines and single wire telephone lines the resistance of the connection from the switchboard to "earth" will occasionally need to be measured, and when the resistance exceeds about 8 to 10 ohms steps should be taken to improve the earth connection. To obtain an accurate result it is necessary that two wires terminating in different offices shall be available. Two tests are made, the first with the bridge connected as shown in Fig. 139, and the second with the bridge connected as shown in Fig. 140. It will be noticed that in the latter case the earthed end of line 2 is in the battery mesh, and consequently the resistance of this earth does not affect the balance.

The first balance gives the following equation :—

$$\frac{a}{b} = \frac{L_1 + y + x}{R}.$$

$$\therefore\ aR - bx = b(L_1 + y)$$

and the second balance

$$\frac{a}{b} = \frac{L_1 + y}{r + x}$$

$$ar + ax = b(L_1 + y)$$

$$\therefore\ ar + ax = aR - bx$$

$$x = \frac{a(R - r)}{a + b}.$$

It is advisable to arrange for the same strength of current to pass to earth in the two tests and in the same direction, as shown in the figures. For this purpose the strength of the current in the battery circuit can be ascertained by means of a detector or milliampere meter, and the voltage of the battery in the second test be increased until the same current is indicated.

Localising the Point of Fracture or a Bad Joint in an Underground Cable.—Where the faulty joint proves to be a total disconnection the test already described for a "dry" joint is not applicable, and it is necessary to employ a method depending upon the wire to wire capacity on short lines or on the impedance on fairly long lines. Consider the following theoretical diagram.

If an alternating current of audio frequency, say 800 periods per second, be applied to the bridge and the resistances a and b be adjusted till balance is obtained, then—

$$* \frac{a}{b} = \frac{\frac{1}{K_1\theta}}{\frac{1}{K_2\theta}} = \frac{K_2}{K_1}$$

* For the meaning of θ see Chapter XV.

where K_1 and K_2 are the apparent wire to wire capacities. Since the wire to wire capacity of a uniform twisted pair of conductors varies directly as the length and the same is true of the resistance, in localising it is only necessary to know the values of the two resistances from the bridge to the fault. Knowing, therefore, the resistance of the loop joined to the telephone receiver we have

$$\frac{a}{b} = \frac{K_2}{K_1} = \frac{R_2}{R_1}.$$

If the resistance of the loop be 2L, then—

$$\begin{aligned} 2L &= R_1 + R_2 \\ 2L - R_2 &= R_1 \\ \frac{a}{b} &= \frac{R_2}{2L - R_2} \\ 2aL - aR_2 &= bR_2 \\ R_2 &= \frac{2aL}{a + b} \end{aligned}$$

ohms where R_2 is the resistance to the fault.

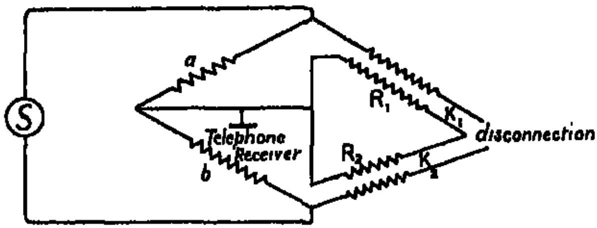


FIG. 141.—Theoretical Diagram of Connections used in Localising Point of Fracture, etc.

It is assumed in this test that the ratio arms *a* and *b* have no distributed capacity and that no capacity effects are produced by the testing officer's movements when making the balance. Ordinary double wound resistances are consequently not reliable as they generally possess a small distributed capacity. It is advisable to earth wire the testing set to prevent any capacity effects due to the movements of the testing officer. The universal fault locator made by Messrs. Sullivan is fitted with non-reactive ratio arms and is wired so as to be free from the capacity effects referred to above. Fig. 142 is a photograph of the universal fault locator and Fig. 143 and Fig. 144 are explanatory diagrams. Two dry cells energise a buzzer which supplies an interrupted current to the screened transformer E. The secondary of the transformer feeds the fault locator which is arranged on the Wheatstone bridge principle, but is fitted with a special vernier on the Thomson-Varley principle, enabling contact to be made by the telephone receiver connection to any point from $\frac{1}{100}$th of an ohm to 100 ohms. The other side of

the telephone is joined to the good wire of the faulty pair and also to one wire of another pair, both wires of which are looped with the faulty pair at the distant end. The faulty wire is connected to S_1 and the wire with which it is looped to S. The telephone receiver is of a special and highly sensitive type and fitted with a short-circuiting switch. It will be seen from the photograph that two switches are arranged concentrically. The outer switch A reading in tens is operated by turning the milled nut, and the inner B reading in units by operating the milled handle. C reads in tenths and D in hundredths of an ohm. Adjustment is effected first with A until minimum sound is heard, then with B, C, and D in order, the balance point occurring when no sound is heard in the telephone. The following equation which is of the same form as that given on page 334 then holds—

$$\frac{2L(a + b + c + d)}{100} = x \text{ ohms.}$$

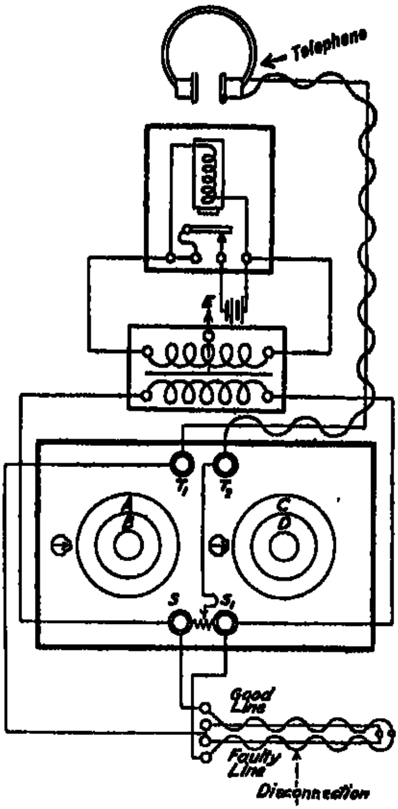


FIG. 143.—Explanatory Diagram of Fault Locator.

$(a + b + c + d)$ is the fault locator reading, 100 the resistance of the fault locator, 2L the resistance of the loop joined to the telephone, and X the resistance of the portion of faulty line from the testing end to the fault. Having made one balance the connections on S and S_1 are transposed and another balance is found in the same way as before, the formula in this case being

$$\frac{2L(100 - [a + b + c + d])}{100} = X \text{ ohms.}$$

It is advisable to repeat these two tests at the other end of the loops and to take the mean value of the four results. The value found in the second set of tests is, of course, L − X from which X is readily found. This test is found in practice to give excellent results on lines up to about 5 miles in length. Where the length much exceeds

this value it is necessary to replace the telephone by a ballistic or special type of Sullivan galvanometer and to use a battery in place of the buzzer. When the depression of the battery key ceases to produce a throw on the galvanometer the fault locator reading is noted, and the same equations as previously given apply.

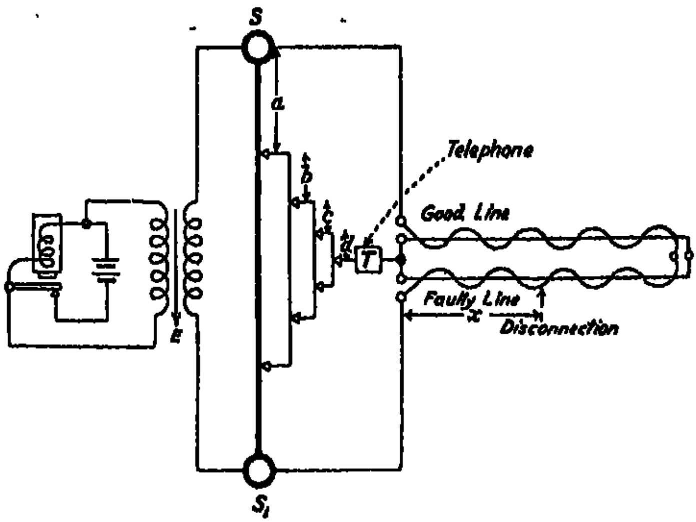


FIG. 144.—Explanatory Diagram of Fault Locator.

LOCALISING INCIPIENT FAULTS IN UNDERGROUND AND SUBMARINE CABLES

A new method of testing for faults in underground and submarine cables has recently been introduced by the Research Department of the Post Office. The following description of the method, which was developed by Mr. H. T. Werren of the Post Office Research Department, is an extract from Post Office Technical Instructions, and is published here by permission of Colonel T. F. Purves, O.B.E., Engineer-in-Chief to the Post Office.

The Localisation of Low Insulation Faults in Underground Cables

Introduction

The extended use of underground cables for trunk telephone lines, which has followed the introduction of the superposed telephone circuit and the telephone repeater, has made necessary a higher standard of cable maintenance than has hitherto been required.

The minimum insulation resistance specified during construction is 10,000 megohms per mile per single wire when tested against all other wires in the cable earthed.

Periodical maintenance tests are made with a 500 volt constant pressure megger. The maximum scale reading of this instrument

is 1000 megohms so that the presence of a low insulation fault, even in its earliest stage, can be detected.

By modern methods such a fault can be accurately localised in its incipient stage, that is when its resistance is of the order of several hundred megohms, thereby making it possible to remove the fault before it has developed sufficiently to interrupt traffic. This results in considerable economy by avoiding the loss of revenue which would be caused by a complete breakdown of the cable, and also by reducing the extent of the damage occasioned by the fault and the consequent cost of repairing.

Theory of Localisation Tests.—The method adopted for the location of incipient low insulation faults in long distance underground cables is the well-known Varley loop test, but the formula ordinarily used to calculate the position of the fault has to be modified to allow for the insulation resistance of the "faulty" wire being comparable with the insulation resistance of "good" wire chosen for the test.

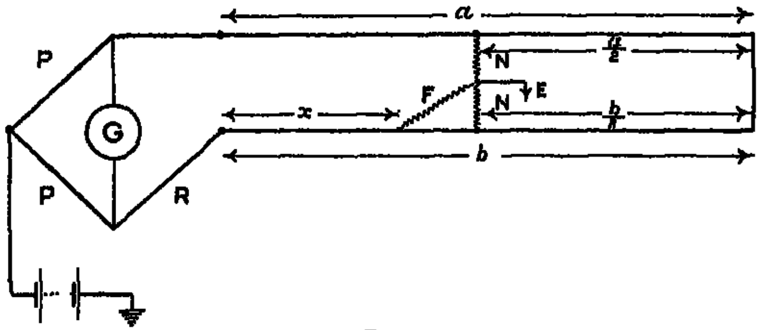


FIG. 145.

There are three cases to be considered depending upon the degree to which the fault has developed.

Case I.—When a fault is detected in its very earliest stage, there may be some wires in the cable unaffected by the fault which will have their normal insulation resistance. The "good" wire chosen for the test will then have its normal insulation resistance N, which may be considered, without appreciable error, to be lumped at the centre of the line. In this case, however, the fault resistance F will probably be comparable with the normal insulation resistance N, and the conditions under which the localisation test is made will be as shown in Fig. 145, in which,

Normal insulation resistance of "good" wire	$= N$
" " " " "faulty" "	$= N$
Resistance of fault	$= F$
Conductor resistance of "good" wire	$= a$
" " " "faulty" wire	$= b$
Resistance to fault measured along "faulty" wire	$= x$

With equal ratio arms PP, and when the conductor resistance is negligible compared with the resistance of the fault, the condition for balance on this bridge can be shown to be—

$$x = \frac{a + b - \mathrm{R}}{2} - \frac{\mathrm{F}}{\mathrm{N}}\left[\frac{b - a}{2} + \mathrm{R}\right] \quad . \quad . \quad (1)$$

where R = balancing resistance in bridge.

The quantity $\frac{\mathrm{F}}{\mathrm{N}}$ cannot be measured accurately in practice, but if a test be made from the other end of the line and the balancing resistance is R_1, we have,

$$b - x = \frac{a + b - \mathrm{R}_1}{2} - \frac{\mathrm{F}}{\mathrm{N}}\left[\frac{b - a}{2} + \mathrm{R}_1\right] \quad . \quad . \quad (2)$$

From equations (1) and (2) the term $\frac{\mathrm{F}}{\mathrm{N}}$ can be eliminated and the following expression obtained :—

$$x = \frac{a + b - \mathrm{R}}{2} - \frac{a - \dfrac{\mathrm{R} + \mathrm{R}_1}{2}}{b - a + \mathrm{R} + \mathrm{R}_1}\left[\frac{b - a}{2} + \mathrm{R}\right] \quad . \quad (3)$$

Case II.—When the fault further develops all the wires will become affected and will have an insulation resistance lower than

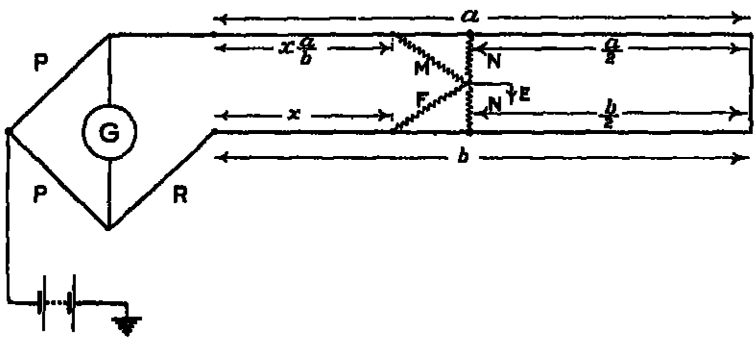


FIG. 146.

the normal. In this case the "good" wire chosen for the location test will also have a fault upon it, and it is safe to assume that this fault is at the same point along the length of the cable as the fault on the "faulty" wire.

Suppose the resistance of the fault on the "good" wire is M. Then M may be comparable with F, and both M and F may also be comparable with the normal insulation resistance N. The conditions under which the location test is made will then be as shown in Fig. 146, in which,

Normal insulation resistance of "good" wire $= N$
" " " "faulty" wire $= N$
Resistance of fault on "good" wire $= M$
" " " "faulty" wire $= F$
Resistance of "good" wire $= a$
" " "faulty" wire $= b$
Resistance to "fault" measured along "faulty" wire $= x$
" " " " " "good" wire $= x\frac{a}{b}$

With equal ratio arms PP, and when the conductor resistance is negligible compared with the fault resistances M and F, the condition for balance on this bridge can be shown to be—

$$x = \frac{a+b-R}{2} - \frac{F}{N(Mb-Fa)}\left[\frac{b-a}{2}\{Mb+N(a+b)\} + \frac{R}{2}\{2mb+N(a+b)\}\right] \quad (4)$$

If a test be made from the other end of the line and the balancing resistance is R_1, then

$$b - x = \frac{a+b-R_1}{2} - \frac{F}{N(Mb-Fa)}\left[\frac{b-a}{2}\{Mb+N(a+b)\} + \frac{R_1}{2}\{2Mb+N(a+b)\}\right] \quad (5)$$

From equations (4) and (5) the term $\frac{F}{N(Mb-Fa)}$ can be eliminated and the following expression obtained:—

$$x = \frac{a+b-R}{2} - \frac{\left(a - \frac{R+R_1}{2}\right)\left[\frac{b-a}{2}\{Mb+N(a+b)\} + \frac{R}{2}\{2Mb+N(a+b)\}\right]}{(b-a)\{Mb+N(a+b)\} + \frac{R+R_1}{2}\{2Mb+N(a+b)\}} \quad (6)$$

To evaluate equation (6) the values of M and N must be known. These values cannot be determined precisely in practice, but if wires having the same resistance be chosen for the test so that $a = b = l$ (say), then equation (6) reduces to

$$x = \frac{2l-R}{2} - \left(l - \frac{R+R_1}{2}\right)\frac{R}{R+R_1} \quad . \quad . \quad (7)$$

and the value of this expression can be accurately determined.

Case III.—When the fault has still further developed it may be that the resistances of the faults M and F are no longer comparable with the normal insulation resistance N. In this case, using the

same nomenclature, the conditions under which the location test is made will be as shown in Fig. 147.

With equal ratio arms PP, and when the conductor resistance is negligible compared with the fault resistances M and F, the condition for balance on this bridge can be shown to be :—

$$x = \frac{a + b - \mathrm{R}}{2} - \frac{\mathrm{F}(a + b)}{\mathrm{M}b - \mathrm{F}a}\left[\frac{b - a}{2} + \frac{\mathrm{R}}{2}\right] \quad . \quad . \quad (8)$$

and if a test be made from the other end of the line and the balancing resistance is R_1

$$b - x = \frac{a + b - \mathrm{R}_1}{2} - \frac{\mathrm{F}(a + b)}{\mathrm{M}b - \mathrm{F}a}\left[\frac{b - a}{2} + \frac{\mathrm{R}_1}{2}\right] \quad . \quad (9)$$

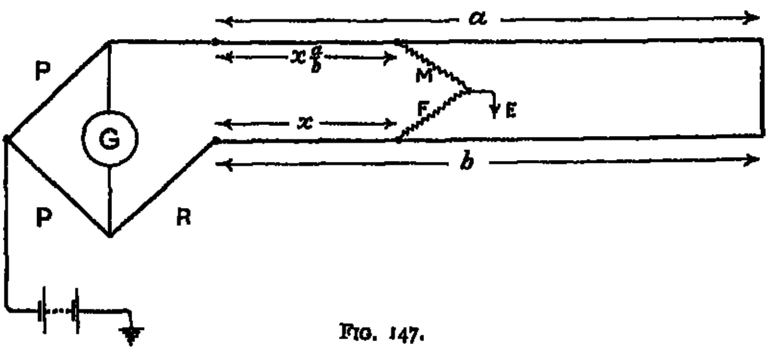


FIG. 147.

Eliminating the term $\frac{\mathrm{F}(a + b)}{\mathrm{M}b - \mathrm{F}a}$ from equations (8) and (9) the following expression is obtained :—

$$x = \frac{a + b - \mathrm{R}}{2} - \frac{a - \frac{\mathrm{R} + \mathrm{R}_1}{2}}{b - a + \frac{\mathrm{R} + \mathrm{R}_1}{2}}\left[\frac{b - a}{2} + \frac{\mathrm{R}}{2}\right] \quad (10)$$

From equations (3), (6), or (7) and (10) it will be seen that the formulæ which give the true position of the fault are different in the three cases considered. In practice it is often impossible to say which of the three cases applies in any particular test, and also there cannot be said to be a clear dividing line between the three cases.

If, however, the condition $a = b = l$ (say) be applied to Case I. and Case III., equations (3) and (10) will both reduce to—

$$x = \frac{2l - \mathrm{R}}{2} - \left(l - \frac{\mathrm{R} + \mathrm{R}_1}{2}\right)\frac{\mathrm{R}}{\mathrm{R} + \mathrm{R}_1} \quad . \quad . \quad (11)$$

This expression is identical with equation (7) which was obtained by applying the above condition to Case II.

In locating incipient low insulation therefore it is necessary to choose for the "good" and "faulty" lines, wires which have approximately the same resistance. Equation (11) will then give the true position of the fault in all cases.

It will be seen that equation (11) consists of two terms. The first term, $\frac{2l - R}{2}$, is the ordinary Varley loop formula and may be said to give the "apparent position" of the fault. The second term is a "correcting factor" and is equal to the error introduced into the ordinary Varley loop formula when the insulation resistances of the "good" and "faulty" lines are comparable.

When the insulation resistances of the "good" and "faulty" wires are not comparable this "error" will vanish, since in this case l will be equal to $\frac{R + R_1}{2}$. Equation (11) will therefore give the true position of the fault under all conditions.

For ease in evaluation this expression will further reduce to—

$$\frac{x}{l} = \frac{R_1}{R + R_1} \quad . \quad . \quad . \quad . \quad (12)$$

And since in a uniform line, the distance to the fault is given by,

Distance to fault $= \frac{x}{l} \times$ length of cable.

$$\therefore D = \frac{R_1}{R + R_1} L \quad . \quad . \quad . \quad . \quad (13)$$

where D = distance to fault, and L = length of cable.

In arriving at the above formula it has been assumed that the normal insulation resistance N of the "good" and "faulty" lines is the same. In a well-maintained cable this is generally true, providing the wires have the same conductor resistance, i.e. that they are of the same gauge and are chosen from the same layer in the cable, and also that the test is made with the battery earthed as shown in Figs. 145, 146, and 147.

It is often impossible on long lines to obtain satisfactory results with the battery earthed on account of the variations in the potential of the earth along the route, such variations charging and discharging the two lines connected to the bridge at unequal rates and causing fluctuations in the galvanometer reading.

Instead of earthing the battery in such cases, the test should be made by connecting the other wire of the faulty pair to the battery, and considering that the fault exists between the wires of this pair instead of to earth. When this is done the other wire of the "good" pair should also be connected to battery, as only then can the normal insulation resistances of the "good" and "faulty" wires be assumed to be equal. Moreover, since when locating incipient low insulation faults (i.e. faults having a resistance of several hundred megohms)

the potentials of the two wires joined to the bridge are very approximately equal, the normal insulation resistances of the "good" and "faulty" pairs may be assumed to be the same, whatever the potentials to earth of the wires may be during the test.

The general arrangement when testing with an insulated battery is as shown in Fig. 148.

It will also be seen that the accuracy of the result depends upon the fault resistances M and F remaining constant during the tests taken from each end of the cable. It will be found in practice that these fault resistances vary considerably when the testing voltage is applied, and this is especially the case when the fault resistances are very high.

In order to reduce to a minimum the error introduced by variations in the fault resistance, the interval between the tests from the two ends of the cable should be as short as possible, and repeated tests should be taken alternately from each end of the cable to

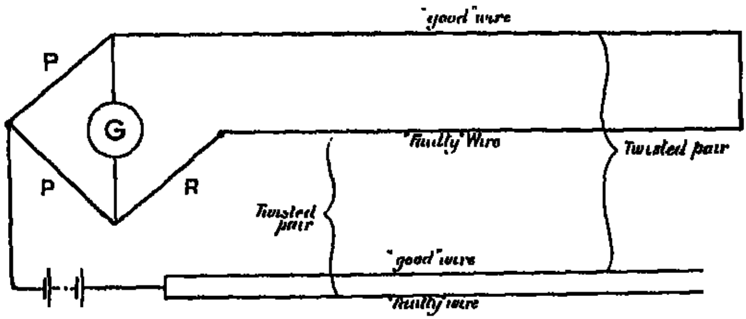


FIG. 148.

obtain concordant results. If this is done it is possible to locate a fault of several hundred megohms resistance to within about 0·2 mile on a cable say 100 miles in length.

In this connection it should be mentioned that when the testing voltage is first applied the cable may take a considerable time to become fully charged, and until the charging is complete the true value of balancing resistance R will not be obtained. If the fault resistance remains constant it will be found that R will steadily increase in value with time until it reaches a final steady value when the cable is fully charged. This phenomenon is due to the unequal rates of charging of the "good" and "faulty" wires, and produces the same effect as a zero error of the galvanometer. A false value for the resistance (R) required to balance the bridge will therefore be obtained until such time as this zero error becomes negligible, i.e. until both lines connected to the bridge are almost completely charged. The larger the value of R, the longer will this take, and in some cases 1½ hours may elapse before a true reading for R is obtained.

In order, therefore, to obtain alternate tests from each end of the line with as short an interval of time as possible between them, it is necessary to keep the lines charged during the whole period of testing, and not to discharge the line in the interval between the tests from each end of the cable. The first test may take from one to two hours, but subsequent tests can follow in rapid succession.

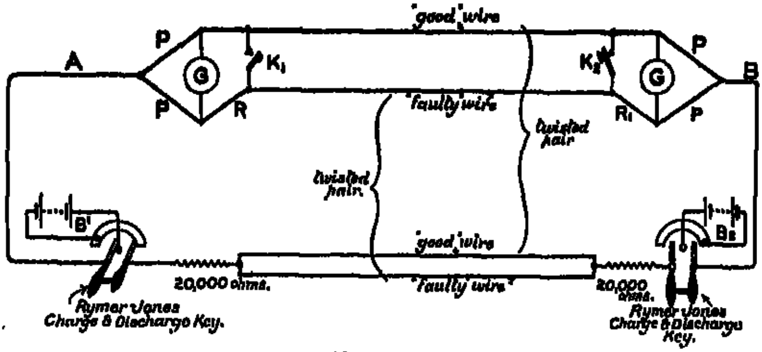


FIG. 149.

Fig. 149 shows the arrangement of apparatus. When testing from the end A, key B_1 is in the "charge" position and key B_2 in the "insulate" position, while key K_1 is "off" and key K_2 is "on."

When testing from end B, the battery at this end should be switched on *before* the battery at A is insulated. Key K_2 is then switched "off" and key K_1 is switched "on." Care should be

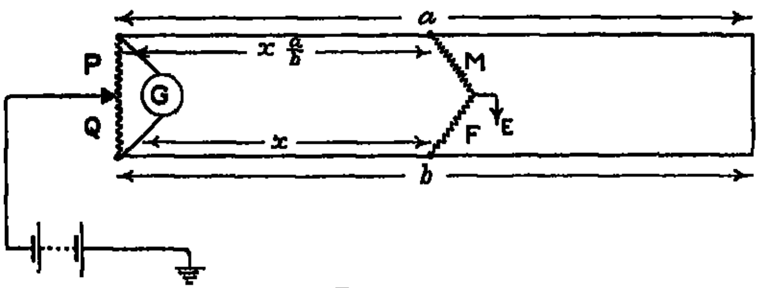


FIG. 150.

taken to ensure that the batteries are of the same voltage and that the same polarity is applied to the centre of the ratio arms at each end of the line.

Tests on Short Lengths of Cable.—In order to find the exact position of a low insulation fault it may sometimes be necessary to make tests on a short length of cable. For this purpose the Murray loop test should be used, the bridge in the Varley loop test being replaced by a slide wire.

On a short length of cable the normal insulation resistance N

will be so high in comparison with the fault resistance, that the only case to consider is as shown in Fig. 150, in which,

Resistance of fault on "good" wire	$= M$
" " " "faulty" wire	$= F$
Resistance of "good" wire	$= a$
" " "faulty" wire	$= b$
Resistance to fault measured along "good" wire	$= x\frac{a}{b}$
" " " " " "faulty" "	$= x$

The bridge is balanced by adjusting the slider on the slide wire, and if P and ϕ be the resistances on either side of the slider the condition for balance can be shown to be—

$$x = (a+b)\frac{\phi}{P+\phi} - (a+b)\left[\frac{F}{M - F\frac{a}{b}} \cdot \frac{P}{P+\phi} - \frac{F\frac{a}{b}}{M - F\frac{a}{b}} \cdot \frac{\phi}{P+\phi}\right] \quad (14)$$

If a test be made from the other end of the line and corresponding values P′ and ϕ' are obtained, and if a similar slide wire be used so that $P + \phi = P' + \phi'$, the terms in equation (14) involving the fault resistances M and F can be eliminated, and we have:

$$x = (a+b)\frac{\phi}{P+\phi} - \left[\frac{\frac{P - \frac{a}{b}\phi}{P+\phi}\{a(\phi+\phi') + b(\phi' - P)\}}{P + P' - \frac{a}{b}(\phi+\phi')}\right] \quad (15)$$

In equation (15), the first term is the ordinary Murray loop formula, while the second term gives the magnitude of the "error" due to the insulation resistances of the "good" and "faulty" wires being comparable.

If the "good" and "faulty" wires chosen for the test have the same resistance, that is, if $a = b = l$ (say) equation (15) will reduce to,

$$x = 2l\frac{\phi}{P+\phi} - \frac{P-\phi}{P+\phi}\left[\frac{l(\phi+\phi'+\phi'-P)}{P+P'-\phi-\phi'}\right] \quad . \quad (16)$$

and since it has been assumed that the tests from each end of the line are made with similar slide wires so that $P + \phi = P' + \phi'$, equation (16) will still further reduce to

$$x = \frac{P' - \phi'}{P - \phi + P' - \phi'} \quad . \quad . \quad . \quad (17)$$

or if D = distance to fault, and L = length of cable—

$$D = \frac{P' - \phi'}{P - \phi + P' - \phi'} L \quad . \quad . \quad . \quad (18)$$

Apparatus used for Tests

Varley Loop Test.—(1) *Highly Sensitive Reflecting Galvanometer.*—It will be appreciated that since the magnitude of the current in the bridge is controlled by the insulation resistance of the wires under test, the current will be extremely small and a very sensitive galvanometer will be required in order to obtain accurate results.

(2) *Galvanometer Shunt.*

(3) *Wheatstone Bridge.*—The bridge will be at a high potential during the tests and connected to lines having considerable capacity. It should, therefore, be of the dial pattern so that it can be operated without risk of accidental contact by the observer, which would result in severe shock and possible damage to the galvanometer.

(4) *Battery Charge and Discharge Key.*—This should be a well-insulated key with terminals mounted on ebonite pillars, of the Rymer Jones or other suitable pattern.

(5) *Galvanometer Short-circuiting Key.*—This key should also be well insulated with terminals mounted on ebonite pillars.

(6) *High Voltage Dry Cell Battery.*—The voltage of the battery should not exceed 500 volts when testing main trunk cables.

(7) *High Resistance of at least 20,000 ohms.*—This should be incorporated in the battery circuit (see Fig. 149) to limit the charging (and discharging) current to a safe value when switching the battery on (or off). This is especially important when testing loaded cables. It will also protect the apparatus in the event of the cable breaking down during the test.

(8) *Paraffin Blocks.*—It is important, particularly when locating faults of several hundred megohms resistance, that the insulation resistance of the testing apparatus should be maintained at as high a value as possible. Any unbalance of leakage in the testing apparatus will cause a zero error of the galvanometer which may give rise to an error in the balancing resistance R, amounting to several ohms, and a corresponding inaccuracy in the location of the fault. The insulation of the testing apparatus can conveniently be maintained by mounting the whole of the apparatus, including the battery, on paraffin blocks, the leakage surfaces of which have been cleaned by the application of a hot iron. High insulation testing leads should also be used, and gutta-percha insulated leads are recommended for this purpose. It is an advantage to wax the ends of all leads for a length of about 6 inches, and care should be taken not to handle this portion of the leads after waxing.

Murray Loop Test.—For the Murray loop test the apparatus enumerated above will be required, except that the bridge will be replaced by a slide wire. A suitable form of slide wire is one

made on the Kelvin Varley principle, the adjustment being affected by the operation of dials.

As an example of the application of the foregoing test the following localisation of a fault in a continuously loaded submarine cable will illustrate the method followed by the Post Office. The details are taken from Post Office records. The cable was 10 nauts in length and consisted of 28 wires made up in 7 quads. When finally tested at the makers' works the insulation resistances of the 28 cores gave the following results after correction to 75° F. in naut megohms :—

Core Number.	Insulation Resistance.	Core Number.	Insulation Resistance.
1	3689	15	3497
2	3421	16	3838
3	3523	17	3578
4	2314	18	4000
5	3550	19	3935
6	3935	20	3935
7	4000	21	4000
8	4106	22	4070
9	1548	23	3870
10	4106	24	4070
11	2810	25	3838
12	4216	26	3870
13	3631	27	3778
14	3935	28	3838

It will be noticed that core No. 9 gives only about half the insulation of the other cores, and core No. 4 also is much below the average. Localisation tests were made and the results pointed definitely to a fault in both cores at approximately the same point along the cable. As the point localised was within a few yards of the place where a joint had been made, it was decided to cut the cable at the joint. On testing the two sections it was found that the faults had been cut out, and on rejointing the cable the following insulation figures were obtained :—

Core Number.	Insulation Resistance.	Core Number.	Insulation Resistance.
1	3583	15	4416
2	3174	16	4626
3	4223	17	4857
4	3886	18	4739
5	3397	19	4857
6	4857	20	4857
7	4857	21	4857
8	4416	22	4857
9	3886	23	4518
10	4170	24	3886
11	4857	25	4626
12	4716	26	4518
13	4518	27	4518
14	4626	28	4626

It should be mentioned that the faults caused no unsteadiness in the electrification, and their existence was indicated alone by the lower insulation resistance. Provided that the low insulation of cores 4 and 9 was due to one fault in each instance—which proved to be the case—the figures indicated that at a temperature of 50° F. faults offering resistances of the order of 2000 and 4000 megohms respectively had to be located in a cable in which a good core at this temperature 10 nauts long would give about 2400 megohms. The following details show the procedure adopted. Fig. 151 is a diagram of the connections.

By adjusting R_1 the galvanometer spot was kept at zero. It was found that it took about twenty minutes before the system had charged up and was sufficiently steady for R_1 to remain the same for three consecutive minutes. When this occurred the value of R_1

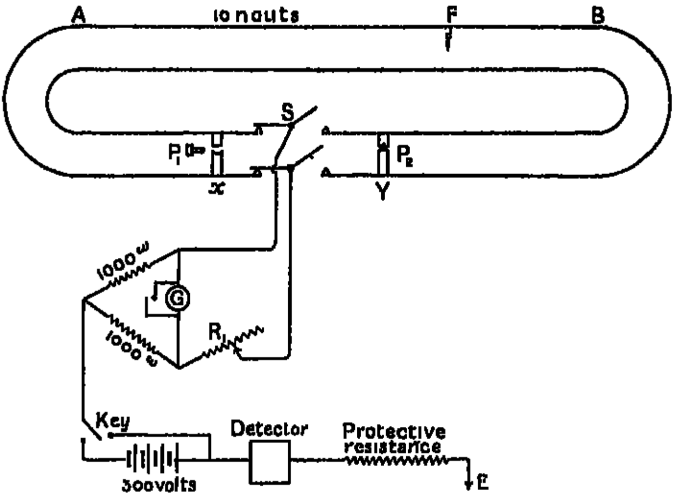


FIG. 151

was noted and the testing apparatus was switched to the other end of the cable. To effect this switch S was changed over plug P_1 put in and P_2 taken out. The galvanometer was, of course, short-circuited while the change was made and the battery left on the cable. The resistance—called R_2 when testing from end B—was adjusted until balance was again maintained for three minutes. Steady readings of R_1 and R_2 were thus obtained from both ends of the cable and the procedure repeated taking tests alternately from each end. The cable continued to electrify for some hours and the values of R_1 and R_2 obtained from alternate ends at about half-hourly intervals showed differences from the previous values which gradually got smaller until R_1 and R_2 were very nearly repeated. When this condition obtained it indicated that the leakages through the fault and through the dielectric of the cores under test were remaining steady.

The distance of the fault from end x in ohms is given by the formula—

$$\frac{R_2 W}{R_1 + R_2}$$

where W ohms is the resistance of the faulty core and its two leads. The value R_1 is the mean of the two readings taken immediately before and after the particular reading for R_2 and *vice versa*.

The following figures were obtained for core No. 9.

(*a*) Core No. 9 looped with good core No. 21.

Resistance of leads only 3·0 ohms.
" " and loop 312·4 "
" half-circuit 156·2 "

Test No.	R_1	R_2	Mean of Test Nos.	Mean of Test Nos.	Calculation.
1	90	—	—	—	—
2	—	131	—	—	—
3	100	—	—	—	—
4	—	145	—	—	—
5	117	—	4 and 6 = 146	—	$\frac{146}{263} \times 156{\cdot}2 = 86{\cdot}70$ ohms.
6	—	147	—	5 and 7 = 118	$\frac{147}{265} \times 156{\cdot}2 = 86{\cdot}64$ "
7	119	—	6 and 8 = 146·5	—	$\frac{146{\cdot}5}{265{\cdot}5} \times 156{\cdot}2 = 86{\cdot}18$ "
8	—	146	—	8 and 9 = 117·5	$\frac{146}{265{\cdot}5} \times 156{\cdot}2 = 86{\cdot}54$ "
9	116	—	—	—	—

(*b*) Core No. 9 looped with good core No. 24.
Resistance leads + loop 312·0 ohms.
" half-circuit 156·0 "

Test No.	R_1.	R_2.	Mean of Test Nos.	Mean of Test Nos.	Calculation.
1	108	—	—	—	—
2	—	134	1 and 3 = 109	—	$\frac{134}{243} \times 156 = 86{\cdot}10$ ohms.
3	109·5	—	—	2 and 4 = 135	$\frac{135}{244{\cdot}5} \times 156 = 86{\cdot}15$ "
4	—	136	—	—	—
5	97	—	—	—	—
6	—	123	—	—	—
7	86	—	—	—	—
8	—	116	—	8 and 10 = 116	$\frac{116}{202} \times 156 = 89{\cdot}60$ "
9	86	—	—	—	—
10	—	116	—	—	—

(*o*) Core No. 9 looped with good core No. 18.
Resistance leads and loop 311·4 ohms.
" half-circuit 155·7 "

During this test the disturbing effect of the shutting down of factory machinery at midday and consequent alteration in local conditions is noticed, and to a less marked degree the effect of starting up again after the luncheon interval.

Test No.	R_1.	R_2.	Mean of Test Nos.	Mean of Test Nos.	Calculation
1	121	—	—	—	—
2	—	157	—	—	—
3	127	—	2 and 4 = 157·5	—	$\frac{157·5}{127 + 157·5} \times 155·7 = 86·2.$
4	—	158	—	3 and 5 = 128·5	—
5	130	—	—	—	$\frac{158}{286·5} \times 155·7 = 85·9.$
6	—	167	—	—	—
7	138	—	—	—	—
8	—	178*	—	—	* Factory shutting down.
9	Jerky	—	—	—	—
10	—	161	—	—	—
11	122	—	—	—	—
12	—	157·5	—	11 and 13 = 120	$\frac{157·5}{277·5} \times 155·7 = 88·4.$
13	118	—	—	—	—
14	—	146·5	—	—	—
15	108	—	14 and 16 = 147	—	$\frac{147}{255} \times 155·7 = 89·8.$
16	—	148*	—	15 and 17 = 110	* Factory starting up.
17	112	—	—	—	$\frac{148}{258} \times 155·7 = 89·3.$
18	—	150	—	—	—
19	—	—	—	—	—
20	—	153	—	—	—
21	119	—	20 and 22 = 153·5	—	$\frac{153·5}{272·5} \times 155·7 = 87·7.$
22	—	154	—	21 and 23 = 120·5	$\frac{154}{274·5} \times 155·7 = 87·4.$
23	122	—	—	—	—

Mean result of fourteen tests of resistance from x to F = 87·33 ohms. Deducting 0·75 for lead x to A gives mean resistance from A to F = 86·58 ohms.

Resistance of core from A to B = 154·5 ohms.

Distance from A to F $= \frac{86·58}{154·5} \times 10 = 5·603$ nauts, the core being 10 nauts in length.

If we take the value 89 for the resistance we get

$$\frac{89}{154\cdot5} \times 10 = 5\cdot76 \text{ nauts}$$

as the maximum.

If we take the value 85·35 we get

$$\frac{85\cdot35}{154\cdot5} \times 10 = 5\cdot52 \text{ nauts.}$$

The joint was made at approximately 5·625 knots so that the mean result is only 0·02 nauts from the joint as determined by these tests, i.e. about 40 yards. Probably the length of the 5·625 knots would not be measured to this degree of accuracy and consequently it was a fair deduction from the tests to assume that the fault was at the joint. The fault in core No. 4 was also localised in the same way and the tests indicated that the fault was at the same place as in core No. 9. As previously stated when the cable was cut at this joint the faults in both cores disappeared.

INDEX